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DOT/FAA/PM-86/31

Doppler Radar Detection of Wind Shear

Transcript of a meeting held at
NASA Langley Research Center
Hampton, Virginia
September 24-25, 1985

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Transcript of a meeting conducted by
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Scientific and Technical
Information Branch

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PREFACE

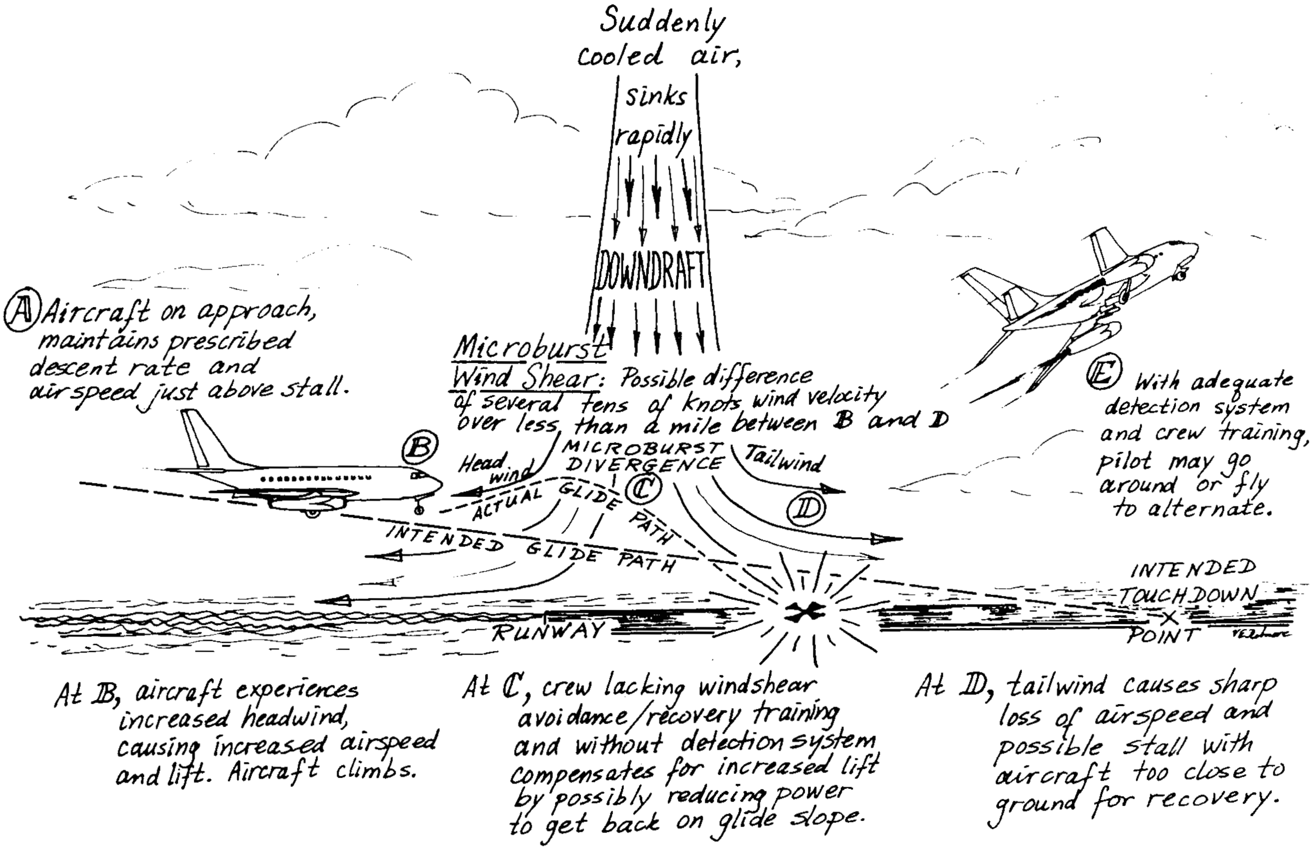
In response to the Nation's needs for decreasing the threat of violent weather phenomena to aviation, a two-day meeting was held on September 24-25, 1985, at the NASA Langley Research Center. This meeting, which brought together representatives from NASA, the FAA, and the avionics industry, focused on the applicability of Doppler radar techniques to the detection of low-level wind shear.

The meeting was cohosted by the Antenna and Microwave Research Branch of NASA Langley's Guidance and Control Division and the Cockpit Technology Branch of the FAA's Navigation and Landing Division.

The publication of the transcript of the meeting is an attempt to make available to interested coworkers the thoughts and views of several recognized investigators in the fields of antenna design, Doppler radar, microscale meteorology, and aircraft operations. A tape recorder was used to make a permanent record of the nearly twelve hours of individual presentations, questions and answers, and discussions; these tapes were later transcribed. The typed pages were reviewed by persons knowledgeable in the jargon, acronyms, and technical expressions used, and then very minor editing was employed for clarity. All persons involved in this process became keenly aware of the frustrating, perplexing, and sometimes humorous differences between spoken English and written English. In many instances a particular sentence structure would sound fine on tape, but the same words, when written out verbatim, turned out to be not a sentence at all, but rather a series of fragments. This was due partly to the greater tolerance that the spoken language enjoys over the written, and partly because in many cases the speaker was either responding to someone else's comment or verbally filling in gaps on a viewgraph. In neither of these two latter instances is a complete sentence required, and because the viewgraph is not available to the reader of the transcript, some information is necessarily lost. Also, on some occasions more than one person was speaking; this usually resulted in a gap, since usually none of the simultaneous voices was sufficiently intelligible for transcription. In other cases, a speaker was just not loud enough to be picked up well by the microphone. Transcription in these circumtances--from tapes, after the fact--poses difficulties analogous to following only the audio portion of a television show.

In spite of these difficulties, it is hoped that the present transcript will be useful to anyone interested in assessing current thinking on the application of Doppler radar to the detection of low-altitude wind shear near airports. The editors of this transcript, in trying to satisfy the competing requirements of clarity and verbatim accuracy, have attemped to preserve some of the spontaneity and interaction between speakers and audience which made this two-day meeting such a lively event.

ORIGINAL PAGE IS
OF POOR QUALITY



Conceptual drawing of wind shear effect.

Campbell: I would like to welcome our visitors from the FAA, NCAR, and Collins to Langley and the Guidance and Control Division. In accordance with Herb Schlickenmaier's (FAA) direction, the purpose of this meeting is to provide an opportunity to discuss the technical issues pertaining to the Doppler radar detection of wind shear for air safety. Hopefully, an informational base will be provided so that a program plan for developing the radar technology for wind shear can be obtained, as well as an assessment of the probability for success of such a program. That is the theme of the meeting and the agenda is as follows: Herb will give an overview of the FAA wind shear program; Leo Staton will present Langley's past efforts and flight test results; Roy Robertson (Collins) will describe current commercially available weather radar systems, and Peter Hildebrand will discuss research ongoing at NCAR. Now, I will turn the program over to Herb Schlickenmaier of the FAA.

Introductions:

Carroll Lytle (Langley)
Vic Delnore (PRC at Langley)
Norman Crabill (Langley)
Glenn Taylor (Langley)
Ernie Millen (Langley)
Jim Shrader (RTI at Langley)
Les Britt (RTI at Langley)
Fred Beck (Langley)
Roland Bowles (Flight Management Division, Langley)
Reggie Holloway (Langley)
Earl Dunham (Langley)
Roy Robertson (Collins Radio)
Herb Schlickenmaier (FAA)
Leo Staton (Langley)
John Fedors (Langley)
Cliff Fricke (PRC at Langley)
Sam Sokol (Langley)
Cliff Hay (FAA)
Peter Hildebrand (NCAR)
Walter Pagels (Teledyne Ryan Electronics)
Ginny McClellan (RTI at Langley)
Tom Campbell (Langley)
Harry Verstynen (FAA at Langley)

Schlickenmaier: At the outset, I'm going to say thank you very much to the Langley crew, specifically to Tom Campbell and his people, and in an overview sense to Langley Research Center for responding to Cliff's request back in April for information and status on a wind shear program. May I compliment you on the package that was put together. It focuses on more than just what's been done, more than just what can be done, but in essence pulls together a good firm program for us, I think, to come up with a very good joint government/ industry program in responding to the safety issue. With that, I'd like to do a quick overview.

You will notice that when Ginny and I were working up the agenda, that there's lots of air in this. I'd like it to be an open forum if we could, and to start it off, I'll just give some introductory information on the FAA's proposed wind shear program that Cliff Hay is responsible for to the administrator. By the time this package comes out, it will be a total package representing the FAA's integrated program on wind shear. It will cross all fields; it will not just be an airborne effort, not just a ground site effort, not just a meteorological effort, but a full-systems approach, we like to think, to the safety problem of wind shear in the terminal area.

With that, let me give you an overview: Overall, there are basically five sections that we are looking at in our report, and you will be among the first to see and hear about this package. First section is the education, training, and operating procedures; it basically looks at the issue of what can we do in terms of training flight crews, what can we do in terms of general education, defining the hazard for the flying community, putting it in perspective.

Secondary is sensors for detection of low-altitude wind shear. This basically encompasses ground site sensing technology, low-level wind shear alerting system, which I imagine most of you have heard of, terminal Doppler weather radar, and integrations of low-level wind shear and TDWR; also applications of the next generation radar, NEXRAD, as we tend to call it, for wind shear detection.

Third section is hazard criteria. By and large, with the background that lives in this room, there is a fair understanding, I think, of what that hazard might be, just like guidance and control systems that you folks have been working on. But there is an overall issue of what is the hazard beyond NASA aircraft, beyond the aircraft that you folks have been working on. I think you'd almost consider it to be an overall question, not just germane to one particular airline or operator, but considered from the FAA's point of view of introducing and having to maintain some sort of regulatory aspect, inspection aspect. We're looking across an entire fleet ranging in terms of what we call Part 121 operations of commercial air carrier operations through air taxi, and eventually, we hope, in Part 91 (general aviation operation)--scanning all the way from small aircraft Part 23, or under 12,500 pounds, through Part 25, air carrier. What is that hazard and how can it be defined?

The fourth section is terminal information systems. Sometimes, I like to think of it as terminal information services. What is available on the ground now?--beyond sensors, moving into the area of how do we get the information to the flight crew from the ground side. I think it's tied very closely with that section by flight management systems. In essence, both of these sections are looking at how you get the best information possible to the flight crew right now. Terminal information systems, for instance, encompasses pilot reports; it encompasses information coming from the center through terminal operations to the tower out to the aircraft, which, as we all know, can be a rather long and arduous task in voice communications.

Flight management systems. Generally, we've broken it down into two areas in the report: guidance and control aids. Basically we're looking at the technology issue we have today and what can we get to soon, tomorrow, and eventually what avenues should we be looking at for some farther down research; how should we be stroking it? And the other area which is peculiar to the FAA, but is an area that I think requires some talking with the technical people, with the engineers and flight management experts, is certification of on-board systems. It's an area that I don't feel particularly well suited to, since I'm not an ops inspector, but with my experience in this program on and off for some number of years with people who do this work, I feel reasonably comfortable in saying that I understand one--programs do not keep the certification and worthiness types abreast of what's going on. Programs that have, I don't want to say, spectacular technical success coming into fruition, but who keep the certification people behind, are programs that by and large (I hate to put a negative note in this), programs that should I say are doomed, and that's an awfully strong word to use. But, if I can put a little personal experience in: in a program from 1975 to 1980, although the flight standards folks, as they were known at the time, were in the group and did understand what was going on--that next step of keeping the certification people involved--they almost in day-to-day operations really didn't quite...out. As a result, some of the recommendations that we made in our earlier programs were thrown in with other projects that were ongoing and were considered in a mass of a wind shear program, all capital letters. Why am I giving this horror story? Well, one of the reasons is that as part of our plan we're putting in programs that are responding to this wind shear hazard. We'll be maintaining a close liaison with the certification people.

To the other question: what is the FAA going to do about certification assistance? In my report, we have certification packages available right now for certification assistance. To date, I know of no company who's come in to apply for a certificate for a system as a wind shear detection and avoidance system. The airborne side has a group of certification guidelines which they work under. None of them, unfortunately, are called wind shear airworthiness certification guidelines, which has given, I understand, to the outside, a source of some consternation.

On the operational side, there is an advisory circular that gives some guidance on operational scruples of airborne wind shear detection systems. A broad brush of what we're looking at; a little background on how this came about: As a result of some National Research Council recommendations, one of the recommendations was that one--the FAA put together a plan to address the wind shear issue; two--to define within the FAA to management all the wind shear activities that are going on. Around April 30th, Cliff put forth a request that you folks are very familiar with--what are you doing, what do you have plans to do, what do you foresee as something that can go forward to address this safety issue of wind shear. The report is referred to as the "3 1/2 inch report," because of its thickness. It's well thought out, and a real credit to the Langley Research Center--a good response to Cliff's request, one of the better packages we received, a collective response to Cliff's request. We then got together about a month ago and basically put the skeleton together--the sections, the format, and to tie it back to the NRC report, to show how we would comply with the NRC's recommendation. Does that mean we're bowing to the NRC?

No. It means that there are recommendations that exist nationally, that Congress asked us to look at. It does give us a good focus of people, with some of the leading aeronautical and systems people in the country.

Second group of recommendations we're responding to are from the National Transportation Safety Board. If you like, I can go into a little bit of detail, but what I'd rather do is open it up to questions.

Staton: What comes after the submission of this plan; is that an "end-all" in itself?

Schlickenmaier: I'd like to think of it is a phase one. We plan to focus all the activities that the FAA can work with. At that point, it goes to the FAA weather coordinator, who also happens to be the FAA's Deputy Associate Administrator for Engineering. Now along with that, all those fifty who responded to the April 30th request will be given a copy of the report. There are no secrets, it's a wide open plan, I'm pretty proud of it. We d like to think of it as a living document; it's not going to specify down to the day when things are going to happen, and as each program plan addresses those issues, this will be a national scope plan. I like to look at it as a living document.

Campbell: You know the planning began on April 30th for the plan, and Langley began, through Roland Bowles, to prepare its submittal, and things began to move down until the Dallas/Fort Worth crash. What are the major impacts of that crash on your planning activities?

Schlickenmaier: By and large, most of the timeline that we have been working hasn't been too affected. There have been some other requests for information...we will be getting a few more requests for information and there will be some Congressional hearings going on that might not be going on but for the crash, but by and large, I don't think it's accelerating it too much. So, by and large, we're still running on schedule.

Campbell: So, this is not a reactionary plan?

Schlickenmaier: Believe it or not, it's not.

Campbell: We haven't seen a major impetus of planning after other crashes.

Schlickenmaier: Although there was an FAA meteorological program underway since about '71 or '72, I hate to think the wind shear program...the Eastern 66 accident at JFK or Pan Am, but I think the biggest effort that was ever put together was a concerted effort, on all parts, beyond just the meteorological work that was going on, but the major emphasis was specifically a response to that accident, involving a lot of people in the FAA. I'd like to throw in just one other thing: in the philosophy of earlier programs, we're not looking for a one-system solution, and I've heard comments from a number of folks that you guys are going to pull together an airborne program.

If you guys can pull together a detection and warning system from the air side, then who's going to be worried about sending advisories from a terminal Doppler radar? If I can digress for a moment and put together a scenario for how I think the whole system ought to be working--I think it highlights the thinking of people who are intimately involved--it basically scopes out an area of the country that needs to be on alert, stage 1 alert; low-level wind shear enhanced terminal Doppler weather radar serves as shorter-term warnings, coupled with what's going on with...advisories, and what's going on with the meteorological situation, and tends to reinforce...wind shear alerting system; see something in the area starting to build up, information is pumped out, and the radar goes, let's say, from the wide scan mode into an approach or departure quadrant scan. The terminal Doppler weather radar starts to see information and the approach or departure quadrant starts to look suspicious--now a stage 3 alert, at which point flight crews are starting to arm the on-board detection system. There are some wind shears that may not be detectable. In essence we're giving ourselves what I hope is a plan of how all the systems can tend to work together; there is no one package. Ten years' experience with the program tells us this.

Crabill: Let me look at the generation beyond. It's possible we're going to need another generation of development in computers, with each major terminal area running its own weather model, running on real time, initialized not only observations that are current, but bigger scale, synoptic scale models. You'd initialize the boundary conditions for each terminal; then that is updated with air reps and terminal Dopplers or NEXRAD; then you'd have the best estimate of what the weather's going to be, so the poor guys in approach control can tell "when are we going to change the runway", that's something they want to know, and also, to have a forecasting facility for some of these major scenarios. Not in this year, not in this generation of computers or of the models, but in 10 or 15 years.

Schlickenmaier: Very good point, which also ties together a reason for focusing the research, now till we start to work using maybe these Cray 99's, putting together new code generation systems. Maybe we can accelerate this 10 or 15 years in the process down to 9 or maybe 13 years. Not necessarily, but what are we focused for? Are we ready in 10 or 15 years to accept systems which...

Crabill: What about the next generation? Can we have forecastability at this time? In 15 years?

Hildebrand: I think you made a very important point there, but as an observationist, I think that I also have to endorse what you just itemized. We need high-density observations and measurements and understandings. There is a lot of emphasis put on wind shear and the like in the Denver area where it's a big problem; the probability of the occurrence is higher of microbursts in any one spot, but the joint probability of having a full airliner and the microbursts is higher in the moist areas; that's where we've had our devastating accidents. So, we need better understanding there in the projects that the FAA has. And that's an important area where I presume that's part of this. The other thing that I think is important to emphasize in addition to better computational capabilities, is that generally, we can't make forecasts with any more accuracy in space or time than in the measurements you make in the first place.

Crabill: I want to talk to you about that. That's not strictly true.

Hildebrand: Well, I know it's not strictly true, but as a general rule, if you look at the global weather predictions, you end up with the density of observations having a lot to do with the accuracy in space and time. And that says a lot about the measurement systems we need, and I think it emphasizes the need for new measurement systems such as terminal Doppler radar combined with better mesonets at airports. I think it's a very important thing to do.

Schlickenmaier: One of the other areas of understanding climatological data makes up one part of the proposal. If an airport planner is going to set up an airport, one of the first things he looks for is where is he going to put his runways? Now, if I were to ask an anemometer installer, who is putting together some sort of a wind system, then I'd want to know what information would he be using to plan the siting, or the locations of where these wind measuring systems would go. It's a convolution of about 4 or 5 different spectrums...But if I were pressed and had to know how many wind shear... then I really feel for the guy. However, it's not an insurmountable project. It would be a project for putting together from statistical, some probabilistic analysis of wind shear worldwide. Basically, just from their Eastern 747, we're talking about a small 10%, but one of the things that tended to reinforce and give us some optimism for the data set was Alan Fuch's response that if we can cooperatively put together similar data sets, the confidence that is gained from that climatological data becomes orders of magnitude, when numbers of countries participated. I throw it out for your consideration. It's going to be quite informative. It's something that since 10 years ago that we think is the right thing to do. It's something we've been wanting to do...We know how many times data reduction and analysis... One of the programs...Some reasons for...computational capability...

Robertson: The program that you have outlined here identifies a number of topics and issues that need to be resolved to resolve the wind shear problem. Does the FAA program and wind shear plan include plans for implementing solutions for these problems that are being identified, and to what extent does the plan do in terms of implementation or development of solutions?

Schlickenmaier: Each program is identified in this plan...On the ground site, where the FAA sees services that need to be provided to the public sector, you will see a concerted effort...On the air side, there is a little difference; we're not providing services for users of the national airspace system as such; however, we have some sort of a developmental obligation...and to that extent...especially if they want to open it up to the...program, with budgetary and financial support. I'd like to assure you in this case that...we're looking at the project manager for the airborne wind shear detection and avoidance system, we're not looking at the division chief, director, deputy associate director, associate administrator, or even the administrator. By and large...we're not talking about NASA Headquarters. We're talking about a cooperative effort between two government agencies and the private sector. I have ways that I can do it, that as far as I know in terms of the budgetary minds in Congress, in terms of justifying myself, in terms of performance of the people I'm working with. But when you talk to people in management positions...really exists. We were serious when we were considering the study group in its initial evolution, we're serious now as we've expanded the scope, we're serious...at the working level.

Unidentified: Are you saying that a major step you see is developing research...radar airborne, but you're not committing now, that that will be implemented on future aircraft?

Schlickenmaier: In the olden days...we were asked to look at the airborne Doppler weather radar program. The program we're addressing now is the airborne wind shear detection and avoidance program. Now, we're all big boys, and we will understand that by and large we're talking about Doppler weather technology applications, but it goes a bit beyond that: not just looking at the development of a research sensor. I'm looking at putting together the pieces that can go into an operational landing system. One of the reasons I talk about verification and inviting some of the manufacturers, is that we'd like to see a package...In essence I am looking at an operational package that is designed to go into a 757 or 767 or even a 737, too. I'm not naive enough to think this can be done all at once. There's a fair amount of research that needs to be done. Some of that, of course, depends on how we're scoping this problem, and how we plan on the intended... Second part of the question, how far are we planning on going with the development, in essence, I think, what we have done in the past, and what I'd liked to be able to do now is show that it is technically feasible, commercially feasible to have a certifiable piece of equipment.

Bowles: You don't need a piece of hardware to do that. You need a research sensor with detailed engineering studies that address that second question. You don't need to build that second piece of hardware within the next X number of years.

Schlickenmaier: From the government's point of view, probably not. What I'd like to be able to foster is to look at a number of ways to do it. What I'd like to be able to look at is an implementation program. So that in essence, we'll keep the government's involvement with the development at a minimum, basically down to the research sensor and to naming the detailed engineering specifications...and going out with a program that says the government, at least from the FAA point of view, will sponsor some of the costs for the development of and flight of this piece of equipment...and then to put it on board an airliner.

Bowles: Let me add one thing that I think is significant. This is based on my travels and experience in this community. Out there on the airplane side of the issue, some highly placed and significant people feel that wind shear is at the top or the top in terms of issues facing aviation safety. So we're not working a normal problem, it's pretty significant. The other thing that I would like to point out is just from a casual overview--well, actually some mandatory reading that Cliff gave me over the weekend--it seems to me that what we're talking about, and there are good words in there on a system approach to the problem, with the thrust really being from a technological given point of view. What can we do to enhance LLWAS? What are the options of terminal Doppler and the airborne options? I say that because what I want to talk about embraces that dimension to some extent. I'd like to get your feedback, so please feel free to interrupt. Back in January, Cliff Hay started his traveling throughout the country and came down to Langley and said "What are you guys doing in wind shear?" It turns out that when we sat back and reflected on it a bit, it turned out that a number of things were going on, and we spent about a month and a half getting into all the principal players here. As Cliff's exercise began to build, February and March time period, it became clear that there was going to be a need to pull together for some information. And being basically a lazy guy, and realizing that a lot of work was involved, I tried to get out among some people and say from a Langley perspective, can we hang our work on a structure that really goes at identifying and elaborating what we're currently doing and building on that technology basis to get at some of the more, or driving towards the solutions, really, to the hazards of flight posed by low-altitude detection wind shear? And we did that, and in the process it involved a couple of directorates, and three divisions, and five branches. It was quite a nice exercise to pull together all this stuff from dissimilar points of view.

The first question we asked ourselves was "Did we have a program?" and the answer was no, we did not have a focused program. The second question we asked was "Do we want one, or should we have one?" and the answer was yes. The third question was obviously "What should the program be?", and that's what you're going to hear about.

I'm not going to make this a viewgraph thing here, because, as Leo pointed out, we've got some real technical stuff to get at, so I'm going to try to highlight what we've done. When we look at ongoing and approved efforts at the center we have work going on in five areas approved of at the top level: hazard characterization, airborne Doppler radar (a program that Leo will elaborate on), simulation of weather hazards, the aerodynamic penalties due to heavy rain effects, and flight controls--all approved and funded at some level at OAST. Whereas this work is excellent and the collection of this activity forms basic technology development trends, it did not really address in a coordinated way or drive towards solutions from a systems point of view. So, we choose in building our proposal to build on that technology base, driving towards a systems-level R&D program with future emphasis on the development and demonstration of candidate detection warning avoidance, wind shear risk reduction systems.

Now, from our perspective, the four key factors were: sensors, hazard criteria, flight management system, and procedures. Now from the point of view of sensors, we have at this center the opportunity and a demonstrated capability with two airplanes to penetrate low-altitude wind shear, namely the severe storms airplane that has a long, distinguished record in that area and a very flexible and programmable flight management system embedded on a 737. Clearly, we are not saying that we can go fly into hazardous conditions with this, but the evolution of the flight management technology should be reflected and targeted towards that kind of system. That particular airplane offers a lot of opportunity in terms of showing and demonstrating what can be done from an end-to-end system point of view, sensitive flight crew, development to ameliorate the hazards of flight. So, we have two opportunities in in situ detection warning, detection and alerting. The airborne Doppler program is an effort that Leo will address. The other opportunity that we have is to make use of the Wallops SPANDAR, S-band radar, which is (on paper) a radar that has characteristics and performance features very much like that being proposed in the terminal Doppler program. What it doesn't have at this point is some of the support processing on the ground, but we think that this will offer a lot of opportunity to test the candidate technology that I will be talking about.

Now with that complement and opportunity of variety of sensor mix, you've got a process thinking of airborne systems; eventually it's the flight crew that we're talking about getting the information to. The behind-the-panel processing, the algorithms, the system thresholds, very complex problems here. You set the system thresholds too low, you get nuisances, crews reject the validity of the process; and you set them too high, you get sucked into the hazards that are conditions at which you may end up with a real performance deficit of the airplane. Flight quality indices for go/no-go decisions and also factor in the effects of the potential hazards of heavy rain in the criteria. That's looking at what is the appropriate sensor mix, what is the processing behind the panel. The other two areas address the complement to that problem. It asks the question fundamentally, "What information should the flight crew have?", "When does he need it in this operational scenario?", "How should it be displayed?", and "How will it be used effectively to manage flight path and control flight path and procedures?" It is very tempting in a technology environment to go deep into any one of these areas. We feel the key is to take horizontal cuts through this sensor mix and unify the systems, with it coming together in the front end of the airplane.

The goal of the program as we are proposing it is to develop and demonstrate the technology for low-altitude wind shear risk reduction through simulation of flight test of candidate flight management system concepts. We propose to do this as a three-phase approach: a baseline system that addresses what can we do in situ for detection alerting, looking at what benefits may be derived from quantitatively assessing the wind shear component along the departure or approach path, and effectively communicating that information from a ground-based Doppler to an airplane; and thirdly, the airborne option, which in itself has many, many attractive advantages if the technology can be achieved.

A theme running through this would be always the information requirements of the flight crew, how to get it onto and integrated into the flight management system. Let me discuss one of those procedures.

There is some work going on in this country, some of it being sponsored by Langley Research Center and one part of it being sponsored by a joint FAA/NASA Langley joint university program, that suggests that these airplanes that we are talking about have an awful lot of performance if we know how to distribute it through the wind shear encounter. In other words, the horror story may not be all that bad if we know how to distribute the performance through the encounter. That requires forward-looking information. So what I'm saying is that the way we are operating airplanes today we know we have problems. Cliff has worked with foreign countries, Boeing, United, in a consortium to look at and improve techniques, and that's good, because that is what you can do in the near term. What we are seeing up here is the opportunity to do better, to ask the question: "What's the best we can do?" How can we achieve that with a forward-look capability is yet to be determined. The story is not all that bleak. Now the other aspect of what we are proposing here is that in this area we also see a strong use of the Wallops SPANDAR to do a multiple Doppler analysis during the verification period of the airborne program, and this also provides independent data sources during the in situ alerting and detecting phase.

Now let me highlight some of the key areas that we see, that constitute some of the basic areas of the effort. I won't go through these in detail; I'll just let you sort of scan them. But these are not to be considered as being in prioritized form or as a definition of the sequence. One of the things that we see to be a key point of focus in the airborne work is that a system ought to be unified to the extent that when airborne radar becomes ineffective for whatever sets of reasons--dry conditions, poor signal-to-noise, or whatever--a system ought to be prepared to gracefully degrade, still providing some information, and that's what we see as basically the reason for starting at the in situ detection and alerting area. For example, what we see here, moving on to the airborne end of the problem, are two key areas, flight deck integration and flight systems technology. Fusing together the available sensor complement with the appropriate information processing backed up by the hazard criteria to transfer information to these two guys who we're trying to do the job for...In the case of where a radar capability may become ineffective for whatever set of reasons, you don't leave a lot of airplane in the hands of a crew with no information. You still do the best you can by fusing the other sensor complement together. We think that's very important, particularly from the point of view of getting acceptance of such a system early on. So, I will make copies of this and give you the details on the specific elements if you like.

In order to do this program, it will take a fair amount of facilities at the center: the 737 airplane and flight research system called TSRV, the F-106, the small administration airplane, the Wallops SPANDAR, the simulator complex, a cloud-scale fluid dynamics model that we put together to study sensitivity of microburst phenomena at various uncertainties, the 4- by 7-Meter Wind Tunnel for the heavy rain effects tests, and the landing loads track.

The way we see it coming together is the concepts development, many of which are in the early stages of formation paralleled by their appropriate sensor development, primarily simulator evaluation of candidate systems in terms of effectiveness of performance; and some of the related applied human factors issues that arise in that area, and finally flight test verification of the most promising system concepts. Again, we would be very careful of how we operate the big airplane in any weather environment.

I don't want to get into the budgetary question here, but what I would like to show you is the current status of the funding levels going into this at the current time. In terms of the ongoing and approved programs, which were the first five that I mentioned, that's the general level of funding in terms of net R&D, and that number has to be looked at sort of carefully. The way NASA works, these are spendable dollars to procure hardware or research products. You've got to multiply that number by two to get the total program value, the overhead, the computer, support service people, etc., and this number does not also include salaries for the staff. Overall, you know, we're talking about something in terms of $1.3 million current effort, which includes the IMS cost. That's what it was in '85, and in '86; the story is there. So that's what the current situation is. Of course, the proposal to carry on with the effort as I've outlined it is unfunded at this point in terms of driving towards the systems program.

Now, let me tell you what I think some of the specific payoffs for the airborne Doppler derived composite system will look like. We've had to put this together at FAA request, and it's a difficult story to make in some respects. I would like to pose what I feel from a flight management point of view, not being a radar guy, what I feel generally moves in the direction of some system requirements. Airborne systems that can detect wind shear ahead of an aircraft represent a technology that has distinct advantages. I don't think we can argue that generic point. Clearly for airports not to be protected by TDWR, certainly supplement TDWR where TDWR exists, which I think is the point that Herb was making--strategic vs. tactical.

Now, yesterday, I talked to John McCarthy, who called me after his Congressional exercise up at Washington last week, and we got into this matter of TDWR and what is likely to be the oeprational mode as he sees it. And I was surprised. I was under the impression that there was a firm position that TDWR was to be an advisory system only. That never would you issue a...to an airplane, based on that system. John is now saying that is false. That you're talking about quantitative information transfer to airplanes. That would provide a basis for a diversionary...clear that up for me, Herb.

Schlickenmaier: That's news. I think to put it in perspective, it might be a goal of what he sees for TDWR. But I think, and I'm speaking out of school at this time, but I'd be very surprised.

Bowles: I'd like to point out as I see it, conceptually, the difference between the airborne option and the ground option. It seems to me that what we're talking about in the airborne case is providing information flow to the captain in command, the guy who can really make the crew feel safe, as opposed to advisory information from whatever sets of forces terminate on the flight deck. And fundamentally, that's a big difference in how you go about engineering these two different alternatives, in my view. I think that's kind of motherhood, but if you think through it just a little bit, there are some fundamental differences in how you go at the airborne wind shear detection warning avoidance system versus the ground system. We think that this proposed program will stimulate and accelerate the development of airborne remote sensor technology on wind shear detection, and there is not a lot that has been done in that area today, in terms of simulation. We all give it good words, but there are very few government resources going into that sensor technology.

We think that the end-to-end system approach that we are laying out, including the flight deck integration, may foster early acceptance by the aviation community, by the carrier operators. You can't really see the magnetron or the waveguide doing this thing, but its product arrives and how you integrate on the flight deck are visible. We think that the integrated systems approach will provide an effective wind shear detection and with redundance of in situ detection warning in cases where radar becomes ineffective. And, one thing I think this group will do is try to understand what's the limiting bounds on the performance of the airborne radar. How many drivers might we see? What is the appropriate signal-to-noise? The point is that if wind radar becomes ineffective in some forward-look mode, we're still talking about a system concept that provides some degree of protection through that mechanism. We think that with 40 seconds of equivalent look-ahead time based on whatever the range gate has to come out for the range of ground speeds at which airplanes approach runways, that a system can be derived with expected performance to recover the 3-sigma cases based on the data base published to date in terms of looking at 3-sigma microbursts.

Finally, we think this system approach will provide a realistic protection system; that is, it will allow the pilot to fly above wind shears or to avoid underflying them. So with that, I'd just like to finish by saying what design features I have on the charts may not be the total system requirements. I think the system should be tailored to flight domain, requiring the maximum wind shear protection, obviously, and where you really want to get that risk reduction. I would argue that that's under 2000 feet of altitude, typically on approaching, landing, and departure targets. And the system has to be looked at in light of the kinds of phenomena that we are trying to reduce risk in. We need to understand the system design against the life cycle characteristics of the microburst landing. When you look at that, I think there is some glimmer of hope. You're talking about 4 minutes in from outer marker. You go back and ask, where can this phenomenon be? Four minutes in the future, or somewhere in the approach path where it threatens me? And you begin to see that the problem in terms of sensing may not be as difficult as we thought. I guess what I'm saying is that we do not need to look off the starboard wing 20 miles and infer wind shear.

The baseline system that we're talking about provides a real time vector wind derived from fusing available onboard in situ measurement devices, both INS or equivalent, and data on the energy state. We've implemented an energy state system on the 737, which is strictly pneumatic, and that one piece of additional information allows us to separate and do a good estimator on vertical wind counts. Without it, you're at the mercy of the other sensor characteristics. The key to that will be an apparent technology wind state estimator, and it would provide an in situ wind shear detection alerting capability.

Now the baseline augmented by and integrated with a forward-look airborne wind shear radar clearly is the direction we want to go. Now, the forward-look radar capability would, it seems to me, have to go out to the measurement of inertial winds on the reference flight path with suppression of aircraft motion components. Peter has done it in your system and also Leo has done it in the early flight test of an airborne radar here at Langley, 1979 and 1982. A 40-second time look ahead based on ground speed provides airspeed recovery, we believe, for the 3-sigma microburst. That's based on the data base that we have available. We believe that it is possible that such a system could be direct-coupled to autopilot mode for wind shear recovery and escape. It requires adequate suppression of ground clutter for approach as well as for quasi state, and for takeoff and departure. And it ought to provide also a scanning capability to go over and look at meteorological areas of interest; that's inherent in the system design. And finally, the integrated system concept should provide for graceful degradation to in situ wind shear alerting mode in certain conditions, therefore retain some degree of protection and reduction from difficult cases for the radar signal--in such cases as wind shear and optically clear air, or air with only blowing dust; some types of dry microbursts, and this number is in dispute, but I have to use a lot of references as I got them. It turns out that we think that 82% of recorded wind shear are wet. Every microburst type wind shear is wet somewhere, and you have to know how to look for them. And we think that 82% is statistically biased towards dry. And the MIST program may actually revise the dry bias. I guess again the question is from a radar-specific point of view, is there some way to get at the question of expected performance in the dry microbursts environment? The FAA has asked for some answers in that area, and that's kind of our response. Perhaps we can do better.

And finally, the system has to be integrated with the flight deck to address the information transferred to people we are really designing it for, the flight crew. So, that's all I have at this point. If we can get back as we go through the day and a half, I have some additional stuff if you want to go into it, but perhaps that would be inappropriate. At this time, I would like to turn it over to Leo. Do you have any questions?

Hildebrand: Just a comment here. It seems like a very well conceived plan and you certainly seem to be aiming at a lot of very good areas. One of the things you mentioned though, and I might have detected a little defensiveness there that I've heard other people mention, that is: dry microbursts versus wet and droughts happen in a dry area. And, my feeling is that the joint probability question of occurrence is something that we should calculate--because that number will show that it doesn't matter. That number will show that even if only 20% of the microbursts occur in wet areas, that 20% is potentially so much more dangerous due to just light traffic loads, etc., that we don't have to worry about that question. And I think we should get rid of that question as a potential thing for people to shoot at this whole program with.

Bowles: I duly noted your comment there, and I have had one discussion with John on this matter, and between him telling me how good his performance was in front of Congress, I didn't really get the information.

Staton: Some people would like us to promise to look at clear air with an airborne radar and we're not quite ready to do that, and I agree with you.

Hildebrand: I think that there is a very reasonable expectation that we can look at wet microbursts with technology we can get to and we know how to get to today. And I think when we look at the direct probability problem in the face we can then say that this is a program that will have enormous economic payoff in spite of the fact that we might not see some of those dry microbursts. I think that is a very important point and I think we should set the issue to rest of worrying about wet versus dry.

Bowles: I couldn't agree with you more, but I've got a feeling that Leo may not completely shake it at this point. I would also suggest that there is an operational asset to this. These things are wet somewhere; in our cloud scale model we see a lot of interesting physics. The physics will give itself away if you could look at them. Now remember, if we define the gaming area of where we want the system to be effective in reduced risks, a prudent operational philosophy would be before you get configured out at the outer marker, to go up and look.

Now, what do we know? We know how long it takes rain in these environments to get to the ground, how long it takes before the outflow diverges. We also know how long it takes the outflow to reach maximum intensity. Remember we're working plus or minus four minutes; that's where there are the hazards of the airplane; it's not at 2000 feet and 250 knots. That's my message, from a non-radar guy. Give me some indication of what the winds are out there, 20, 30, 40 seconds in front and with acceleration capability of 3 knots per second; you can make the airplane do a lot of things. That's my message. But, clearly, I think the other thing that I would not like to see is that in some respects this and the terminal Doppler effort to become, in any sense, competitors or viewed as one or the other being an alternative technology. I think that would be absolutely wrong. I couldn't agree more with what Herb said about that issue, and until we understand the full facts about TDWR to deploy and operate, that even requires that we give this end of the problem a continued look.

Crabill: The idea that you could have an effective airborne Doppler weather radar could change the deployment philosophy for the ground-based terminal radar.

Bowles: Certainly, how you integrate the surface data. Another message: if we don't do it, the French are. The A-320's are already beginning to advertise wind shear protection on the airplane, which eventually you fellows are going to have to wrestle with on an envelope-developed airplane. So, you've got to keep in mind as we talk about the aviation systems it's the guys in the seats up front there that we are trying to provide the information to.

Hildebrand: The Taiwanese are just placing the order for the first terminal Doppler radar at an operational airport in Chiang Kaishek Airport.

Bowles: What might we do in 7 years with huge computer capacities? This is a little study we did based on the August 2nd, 6 PM Stevensville sounding using a cloud scale model. The sounding had all the features, the dry adiabatic boundary layer, a lot of moisture around freezing level, a deep dry pocket above, so we used that to initialize the 3-D prime scale model and put a 3-degree thermal pulse in it. And it produced this microburst. Which is fairly impressive in a way. The vortex rolls are beginning to get a bit of attention, I understand, based on the fellows that unraveled the flight data recorder. And there's even a tendency here to want to generate here a multiple, a cascaded-effect vortex at this particular time. This particular event based on the simulation is a rapidly rising tops to 60,000 feet, a lot of rain, up to 60 dBZ rain contours. So it was a really significant event. We're not saying that this was the Dallas thing, but what we are saying is that this kind of physics on that day can produce this phenomenon.

Staton: We're not talking about well-known, well-established radar technique. We are in a whole new ballgame trying to determine what the wind shear is on the ground looking down on the approach path. It gives some indication that this is different from anything we've done in the past. Some history of our radar program at Langley: two branches that are involved in the radar work now, going back more than 10 years in the microwave remote sensing of all kinds: radiometers, radars, developing the idea of radar analysis for the SEASAT satellite scatterometers, scattering from the ocean surface, Doppler sharpening of the resolution cells to show what is in the small patches in such a way that could be measured, wind vector near the ocean surface could be measured. In reducing radiometer data, we have to take into account the surface roughness. We have a background in looking at scattering from the ground in its barest form. We have people right here in this room who have traveled all over the northern hemisphere making just that kind of measurement. Though we have some feeling for the nature of ground clutter and what it is, we have no feeling up front for the nature of ground clutter as it applies to low-level microburst...The first foray, at least to mind, into airborne radars for meteorological-related activities had to do with the use of the first NOAA P3 delivered around 1977. We were the first customers for that airplane and we procured a copy of the tailsting radome and installed it on the airplane and did some flight testing around Wallops Island even before the X-band tail radome was installed in the P3. The instrument that was in that tail was the dual frequency incoherent radar operating at S-band and K_u-band with matched beam widths. The intent of that program was to make some measurements that would bear on NASA's activities toward a satellite-meteorological radar. Here's a picture of the console of the P3 transmitter and receiver package in a nutshell.

As time went by and interest on that particular application waned, we cannibalized a lot of this radar to produce the doppler radar used to participate with Norm Crabill in the summer of 1982. With those experiments we had a K_u-band Doppler radar mounted in a Shorts 330 aircraft, with the antenna located in a turret-style radome atop the aircraft. It was scannable, but mainly we looked rearward between the twin tails on the skyvan. We looked at situations where we were simultaneously looking at the SPANDAR radar which we operated in the Doppler mode and with the F-106 storm hazard aircraft, flying radial paths into a thunderstorm the same time we and the SPANDAR were looking. The principal characteristics of the radar as it existed at the time were 13.90 GHz, 3000 pulses per second, 2-microsecond pulse length, and the standard 3 degrees beam width that everyone in radar seems to have to live with, and a maximum unambiguous range of about 50 km. The first Nyquist interval is plus or minus 16 meters per second. This turns out to be a pertinent thing that comes back to haunt us with the low-level wind shear problem. With this kind of beam width, at 10-kilometer distance this is the kind of transverse resolution you have to live with. The last, of course, refers to the feature that we developed to put into the radar. It lets us compensate for the aircraft motion: you are looking along the line of flight; therefore the aircraft velocity is a sizable contributor to what we can see in the Doppler spectrum. In this corner you are looking at a storm someplace with some velocity delta with respect to the airplane and has some spectral shape which generally dwells beyond the Nyquist interval three or four times, and what we wanted to do with this instrument was record information on a pulse-by-pulse basis for subsequent data analysis. In the system we had a desk-top computer system implementing the pulse-pair processor algorithm for making the estimate of mean velocity spectrum. We used that to control the VCO on the synchronous demodulator which brought the signal to baseband, such that the spectrum is pulled into the first Nyquist interval. After making the first guess as to what the cruising speed is, we get into the first interval and this hones in on the spectrum and keeps it centered on the first interval by recording the amount of the frequency shift of the oscillator and the time series data; we have all the information there is without being contaminated by the aircraft motion (shows charts). What's shown here is a plan view of two successive antenna beam positions with vectors traced in mean wind in each of the radar resolution cells along the length of these two look directions. Shears involved are important. The idea is we were able to measure the mean velocity from cell to cell with no turbulence reflected in the data and from that we can subtract in both directions and measure wind shear as well as turbulence. The instrument is far from being anything the industry would want to use for packaging standards; it occupies several racks of equipment. The idea is, of course, techniques; not to try and tell people how to do a job they know how to do a lot better than we do. This is what we have done in the past with the Doppler radar. Notice there is no ground clutter in this data. We couldn't see it even if we wished; it is screened by the top of the airplane. We didn't think of it as a problem at the time sitting at 9500-foot altitude. If we were going to do a problem where we try to measure wind shear near the ground, you have to contend with several things. Here's a sketch of the microbursts, and what one radar sees. If you live with one radar, of course you get one cut through this profile. If your job is to recognize a signature of a microburst, assuming one is present, then you have room for these velocity patterns to form in your radar. All the action takes place at very low altitudes near the ground with substantial shears in the wind-driven aerodynamic boundary layer of surface of no wind, and that can increase dramatically in layers and we have got to contend with measuring very strong shears very close to the ground. Relating to what we must do to cope with this problem, this is a sketch of a typical 3-degree beam we can live with on an airplane, and notice that we are 10 kilometers away on a 3-degree glide scope 500 meters up and your resolution cell is also 500 meters wide. Here's the circle on the ground that shows all the other places that are the same range from the radar. All of these cells impact the ground and whatever ground clutter there is in the main beam and added to superimpose on the signal we get from the raindrop; also whatever power there is in the sidelobes has been scattered in these places giving signal back at the same range. Data has been collected historically from instrumented radio towers across the country, from 1500-foot towers. It has been noted that from 50% of the time the passage of a common garden thunderstorm will show a shear greater than or equal to 25 meters per second between the ground and the top of the tower. If you have purely laminar flow, no turbulence at all in here, the fact that the cell is 500 meters high in this case, the same height as the tower, I would say that you are going to see a spectral width corresponding to 25 meters per second. The initial JAWS data doesn't show things being that severe, so I was a little bit comforted by that. This may have not been the whole story, because the lowest cell they were able to measure was at least 75 meters above the ground, so it perhaps did not reflect the entire shear which was actually present looking directly into the cloud. So it is hard to think that in the microburst you wouldn't have situations at least as severe as those of the common garden thunderstorms. I'm convinced we have to work on the situation where we have very broad spectral widths just due to the wind shear alone, irrespective to any turbulence present. Another view of the ground clutter shows you looking ahead of the airplane; you think you are looking at this spot, for example. This spot is moving roughly at the ground speed of the airplane towards you. These lines are the insections of spheres centered on the radar intersecting the ground with both sides constant length. Assuming level flight and looking straight ahead, these could be parabolas on the ground and would be the low side of constant Doppler shift. On the sidelobes you are looking at all these patches of ground out to a given range to whatever extent the sidelobe is significant. It comes at us in all velocities from zero to the ground speed. We have all the problems of aliasing. Just to follow up on some of the things that Roland just said, it turns out if I use his 40-second look-ahead time, I can just change the meters to feet and use the same...From 10,000 feet away, 500 feet high, I have 40 seconds to reach this point, which means that I don't really have to see very far ahead of the airplane I'm landing. I need only 40 seconds to one minute look ahead; I don't need to look very far. If I'm on the ground at the end of the runway ready to take off, I have to see the length of the runway plus the hazards existing beyond. So I can't take a single system and do both the short-range problem and the long-range problem in the sense that I want to take advantage of the distance to be able to pump the PRF up high enough to do something about it. The problem of aliasing still is there, and we have to look at it in some detail even with the relaxed constraint like the one that Roland's suggested we can live with now. This is an old chart; it has some random faults on it, some of them are still pertinent, and at least they are worthy of some discussion. First one I just mentioned, the second one I mentioned, the third one is what we call a signal, other people call a quirk. We are looking at range and there are techniques to suppress range, certainly polarization and all kinds of things. There are techniques for pulling the coherent target from the clutter; what we are dealing with is one kind of clutter buried in another kind of clutter. When we are approaching the runway, the precise airplane speed determines where the main lobe clutter is going to be placed in the lock. They don't have the advantage the ground-based radar has, in that you know you are dealing with a relatively narrow spectral for the width at ground zero velocity. Then you can use pick filters in either the time domain or the frequency domain. In our case, the clutter can wander around; if you don't know precisely where it is and you are not able to find out precisely where it is, then you have got to use filters that are going to either not drive the clutter down as far or they are going to throw away some of the signal. This is a problem that is much more formidable with the airborne radar. This one is worth talking about. I just mentioned that we really don't have to deal with long range on some of these problems. I also mentioned we have a problem with transverse resolution. If you go up in frequency, you can get the correspondingly better resolution. Going up in frequency above X-band is totally unacceptable for the...problem where you have to be able to see many miles ahead of the airplane. On this job it is a disadvantage to go away. There are definitely advantages; there are also serious disadvantages that we want to think of this function as being just an augmentation of the standard weather radar. This is the kind of thing that needs to be studied, the first intense study being done at X-band to see what it will do to get out of there. If it can, great. You can't do the job, at least the studies indicate there may be some tradeoffs that will drive us to higher frequencies than our research program has indicated--like, to see what effect that has on implementation later on. This one is certainly true; it's a problem on the borderline or the boundary line between the radar and the remainder of the system that Roland talked about. Somebody someplace has got to recognize the hazards, and we've got to do this in some sort of automated fashion. To quote what may or may not be an accurate statistic I ran across in one of the papers, an airline pilot can expect to encounter one of these series of events once in a career. Once is enough. If you expect to find these things relatively infrequently, then I don't think we can leave it to a pilot to look at a display and be able to recognize this thing. Somebody has got to automate in some fashion this thing, and at this point in directing our efforts, I'm ready to hand that over to Roland. If the requirement on the radar is that we produce a 3-D map that requires a wind velocity field...

Bowles: I would say that would be a desired requirement that would be unachievable in this decade. Nor would the pilots be able to use it.

(Discussion)

Staton: Given the wind field, you still have to apply some intelligence to say what it means.

Bowles: I don't think so. I think that's what the on-board computer is for.

Staton: Someone still has to program the computer.

Hildebrand: I think there is a problem with what he said in that we have to automate it. I don't think we do; I think we have to provide displays that are interpretable, but just within the last year or two there've been a couple of cases where pilots with wind shear training have responded properly. It's apparent that the pilot who crashed in Dallas had at least some awareness of wind shear training and may have done things wrong, but there are cases where United pilots saved the airplane because of wind shear training and prompt action, doing all the right things. Training can bridge the gap.

Staton: That still is not the same thing as saying, "I have got a single vantage point for a given velocity vector field; what do I do with that information to provide a meaningful display?"

(Background discussion)

Bowles: Simply calculate acceleration for the airplane relative to the air mass based on that situation. That means in the next interval of time you are going to lose or gain airspeed. The point I was trying to make is that if I have got my winds now at time t at this point on the flight path, and I've got some winds in a forward-look mode, let the computer take those two winds, difference it with distance and compare that against the acceleration margin of the airplane and decide whether I've got enough performance to gain airspeed or can I coast, or should I just go.

Hildebrand: I agree if the information is there it should be displayed and you combine that information with training in simulators and teach the pilots how to respond. These approaches fairly work.

Bowles: They are only using them now to derive the on-board winds, compute the acceleration capabilities of the airplane relative to the air mass, and say if the winds stay the same as they are now over some delta t, I will lose 20 knots or I will gain 10 knots. Provide that against a criterion to say you are now to issue an alert or you just don't have enough performance to gain potential airspeed loss.

Unidentified: Roland, if I can insert something about the A-300/310. For your information, as you know, the displays of the wind field... Given two airspeed, ground-speed measurements...between the British and the French and all of us, the wind field airspeed and ground speed. Let me insert one other thing if I may, and this goes right along with the point you're making. Take advantage of these in cremental steps in improvement as we can. Going back to Herb's state ment, in a way this is an open-ended program in which at each level we're able to add an incremental improvement in the system, and should rovide that information or criterion or whatever it may be.

Staton: I can't overplay the last bullet on the chart. Given that the average flyer today sees these things fairly infrequently, anybody that tries to research this problem with an airplane, you have the problem of being in the right place at the right time to see one of these things under realistic conditions. At the end or toward the end of every program we have to come to grips with the fact that we are probably never in the space of any finite time going to truly exercise whatever system we develop before we hand it over to a manufacturer or whoever. Just because the airplane has got to be aloft already, the event is so short-lived that it is troublesome as to how you look at it in all of its glory and if you, as I tried to point out in some of the previous radar stuff we've done, if you are not looking down, looking ahead, looking at this wide wind shear, you are not really looking at the problem, and if you have algorithms that are trying to separate the true effect and you are not really looking at that effect, you don't know if it really works or not. So all we can really promise from the standpoint of the airplane is that we have got to build the program so that at every point we have some confidence in what we have committed to hardware in the program--makes good sense. So we don't do that by just putting together a radar of some kind and getting on an airplane and going to look for a microburst.

Another chart that says what we are trying to do. I think it sort of speaks for itself. The research program that we undertake has to attack those problems that are different from the low-level wind shear from all those other problems. Military systems routinely try to extract targets from clutter, but if you look at those systems, they all have a feature that we don't have. You are either looking for a coherent target in some kind of clutter or you are looking in a wide velocity difference between the target and the clutter. Trying to pound a round radar into a square hole certainly got the Sergeant York missile launch weapon system into trouble lately. What was called a radar that worked well on airplanes (it could pull out fast-moving airplanes from clutter) didn't work very well when you put the heli copter in clutter. That system was a colossal failure, and a large part of that was due to the radar. When we developed this program we specifically got to look at the problem. You can't glibly say that the data we've collected already in platforms looking at thunderstorms is really directly applicable, in my opinion. So what are we going to do about that? Well, we are going to have to develop an approach where we are able to collect realistic clutter data on a time series basis that contains all the information there is about ground clutter. We can generate such stuff on a computer. In the literature, there are enormous quantities on ground clutter, but virtually all the older data gives up at 5 or 6 degrees grazing incidence angle. They don't tell us anything. Such data as you can find has already been massaged and at best is presented in the form of probability density functions for the fluctuating amplitudes that you might see. If you are really going to use that kind of data in a situation where you don't have very long to observe the cell of interest, then you've got to make a quick decision when you are dealing with a reasonably short time series, so you've got to take that probability density function and convert it into something that fluctuates. We know how to do that; we've done that sort of thing in the past. Part of our program is to continue this kind of Monte Carlo computer modeling, both of ground clutter and of raindrop populations. It virtually can be brought over en masse to this problem. This will let us look at the ground clutter alone, ground clutter plus rain that we can put into any kind of wind field that we desire. We rely heavily on Roland's inputs: both the stuff they are doing and their interpretation of what other people are doing, JAWS and so on, to provide us with a realistic wind field. So, by playing extensive computer games, we can on this Monte Carlo basis, get a pretty good idea how serious the ground clutter really is. We can produce the map of clutter and apply a motion to it; we can do some things with a virtual memory on the VAX that would have been a problem a few years ago. With expanded memory, we can now run these cases. We may have to let them run all weekend, but that's not really a serious problem. So, with computer modeling, we can and intend to get a good inroad into the problem. That still, however, is somebody's fantasy of what the world really is. You have got to have some real data to satisfy people. So, since we don't want to try to build a program where we say we are going to fly off with our best shot at an instrument and see if it works, we're still exploring the idea of being able to merge two kinds of data sets. That is, suppose I have my radar on an airplane and I fly approaches to an airport and the ground is wet or dry or whatever, and collect the entire time series history of moving ground clutter. I can take that data and add the computer model to where the raindrops scatter to (we have a fairly good understanding of that sort of thing), and then produce a data base of real ground clutter in a known wind field and see whether our extraction algorithm is workable. The third phase is to use real rain data, maybe collect it in the ground look-up mode to the same radar or an identical radar. If it is stationary on the ground, we are at least emulating takeoff problems; we also have a pretty good chance of suppressing ground clutter almost as well as ground-based radar, not quite as well because their system is designed to be fixed-frequency coherent all the way, and we have to have probably moving oscillators so we won't be able to reach the 50-dB subclutter visibility that people are talking about for NEXRAD. So, in the ground look-up mode, we can look at real rain data, given that something will happen in our vicinity. How do we get such stuff? For that part of the program we will have to participate in a field program not unlike the MIST program or something like it, where there is some truth data available. We don't really want with our resources to commit to fielding our own MIST program, but we would like rather to participate with other people who will be doing that sort of thing. I hope, our schedule permitting, there will still be activity like that going along by the time we...So I mentioned the phase looking up, getting real rain data on a time series basis. We can take those time samples and compare them, or add them to the airborne real clutter data and have a better exercise set for our procedures. In time we have the best shot at what algorithms may work in real time, and then you look for intelligent opportunities to verify them. You still are probably not going to find a microburst. But if you can find low-level shears of any kind, gust fronts, anything you can live with and show that we are able to extract that wind shear from the clutter under more or less realistic conditions, then we have done something. There are elements at Langley who are working on adapting very large scale integrated circuits and very high speed integrated circuits, a fact that the Navy and others are interested in, trying to adapt those techniques to other program demands. That is an ongoing effort independent of this. Some of the suggestions that we make for algorithms...could provide a focus for some of that work and we may be able to parallel, to get a start toward being able to actually have in place computational power which you can put on commercial radar a few years down the road and actually implement it. We envision our airborne radar as looking a lot like the...It will be assembled with simple laboratory equipment of sorts. Once you have a radar that's approaching a runway and it's getting ground clutter data or storm data or whatever, if it has one antenna or one polarization, it's going to give you data for that radar. It's not possible to build a general purpose radar that has all characteristics. What we would like to have, we dream, would be a radar for direct and cross pol, maybe use separate antenna apertures, techniques for cross-correlation between the two for electronic suppression of clutter, all kinds of things you might like to do without going to the open rack construction. We might be able to implement some of those things in second channels to find whether some of these exotic concepts will really offer anything or whether they are a lot like the information theory results a few years ago. People put a lot of time into designing optimal filters and this sort of thing, and once you give it your best shot, apparently you find that you just make your first guess; you'll still be within a dB or two. So, the exotic techniques may or may not be necessary, but we wanted to cover as much as we reasonably can. So, the computer modeling studies are the kind of thing that are going on. Roland showed you that we do have some sort of funding on this job now at NASA HQ, and we are using it to buy some small pieces of equipment, but by and large we are using it to do computer studies. And now we will continue to do that through the next fiscal year. This is sort of a schedule of what we are presently planning. Last year this time we were thinking about getting more quickly into a hardware program, but the FAA's plans, and the funding in particular, were such that we delayed that. Through this next year with the present level of funding, we are going to continue the analytical work and begin the hardware development a year from that, and in the spring of 1988 be ready to go on an airplane. And then some of these combined clutter-rain experiments and by a year following that, we should have some significant flight statistics, and a fairly good idea what the correct approach is. I have spent a lot of time here emphasizing problems, and I don't want to leave a negative note here. Our main purpose in mentioning problems is to point out that we are in a different regime of radar application than in most applications in the past. Not to say that we can't make good progress. The clutter problem may not be as severe as it could be, and we may find ways around the wide spectral width and certain of these other problems. I think there's a good chance that we will make good progress on airborne sensors, but we won't really know that until we carry it to its fullest. One thing that is certain to come out of this work: we will know what the capabilities of practical radars are in this problem. In order for a radar to be practical, it's got to not only work when it takes up three racks of space, but it's got to be implementable into something that we carry. We will know that, and I think we've got a good shot at developing workable techniques.

Dunham: The Doppler technology really got cheated on Roland's first design goal, which was, I recall, 30-second look ahead of the inertial wind field so you can compensate for the motions of the airplane and moving ground clutter. I was wondering if that constraint may not have been for the Doppler technology a little bit too severe and maybe the problem is the same, but let me state it this way. If you are trying to provide to the pilot some indication of winds, like for example, the wind 30 seconds and where I'll be 30 seconds from now is a 20-knot tailwind, you are probably flying in a 40-knot headwind, he can sit there and say, "Boy, that's tough," or if you want to provide him a wind-field display that he can get that type of information out of, that's one type of input to the pilot, but it turns out that from an aerodynamics point of view, the airplane's motion is not with respect to an inertial reference point, but with respect to the air mass. So the airplane doesn't really care what the wind is doing with respect to the ground. You only want what the air mass is doing in the front of the airplane with respect to the airplane.

Staton: That's what the Doppler shift does; to get the inertial winds is another step.

Dunham: What I'm trying to say, do you have to remove the inertial wind?

Staton: No, that's not necessary at all. The main problem with the winds is that you have got to span an interval with your sampling rate to tell you unambiguously what the velocity is with respect to the aircraft, and if you know, for example, that the target you are looking for has a narrow spectrum and even if you are moving, if you know how many times it's been folded, it's no problem. Tracking it out as we did in this other thing is one way to do that automatically so you don't have to worry about it. But so long as you know how many times the velocity has been aliased, if the spectrum is narrow enough and if it doesn't happen to have half of the line on one side and half on the other, you can handle it.

Dunham: What I'm saying is I think the sensor can really get by with detecting a gradient in front of it and not an absolute value and...

Crabill: To do that you've got to do what you say. If what Earl is saying is true, it will simplify it. In order to get back into the gate so you can determine it, you've got to unfold it somehow.

Staton: That can be trivia, but you are dealing with a moving point target. If you know roughly what your speed is, then sure, he's in some other interval and he's finally going to be folded back into your first interval; half of it can lie on the right-hand end and the right half of that will lie on the left-hand end and you've got to apply some intelligence to that, say where to...You've got certain fundamental things to overcome, but basically we are not after looking at inertial winds, we are looking at the gradients.

Bowles: But you don't have to create an inertial reference point. You can do it in the reference frame of the...but what you are saying, your processing problems on the signal are the same.

Staton: Essentially the same.

Bowles: It doesn't ever have to be referenced to a spot on the earth.

Staton: That is if the ground clutter itself comes back relative to a spot on the earth.

Dunham: I think to get rid of the ground clutter, it has to be...

Staton: It's a possibility you can get rid of it there or somewhere else. You have to know by some means where the ground clutter is located. One way to do that is through the open loop using the INS ground speed or integrating an accelerometer, or something like that, and you have to know what your ground speed is, because the ground speed and the dip angle are going to determine where the main lobe is.

Staton: Just because we have no inputs at the start of the program.

Bowles: Yes, but the airplane's velocity is fairly constant and what you are looking for is the rapid changes out in front of you.

Staton: And if you are doing things like that, then you don't have to know anything about the aircraft speed if you are willing to say, I've got a small resolution cell here and one there and one there and one there and I look for the profile.

(Unintelligible discussion)

Roland told me he's not going to make that demand on me. Roland told me the other day that he can be content with a moving cell ahead of the plane.

Unidentified: Well, the one you just described is the one I'm saying is the airplane's dynamic responses; you say that's the easiest task to look at.

Staton: It's a different task, but it still doesn't do away with the ground clutter problem. We've got to know where the ground clutter is in order to control it.

Unidentified: All I'm saying is the reference frame that you choose to work the problem in, whether it be inertial or airplane related, the transformation there, one way of working the problem may be easier than another. I don't understand radar technology, but maybe you could look at it from that standpoint and determine one way is better than another, but the airplane really only responds to the latter case you talked about--what's the gradient in front of me, with respect to me. It doesn't care if it's going 400 MPH on the ground, it's what it's doing in respect to me.

Pagels: I think Roland was referring to the fact that you have an independent way of measuring your airspeed; you know your present airspeed. You don't need the radar to tell you what your airspeed is, although it can be done. But, what you want to know is what is your airspeed with respect to the air mass out ahead of you. So the radar can do the job by looking here and there or it can just look there and you can use an independent airspeed measurement.

Bowles: It never needs to know the velocity of that air mass ahead of you.

Unidentified: That's true, that's just an arbitrary data point.

Staton: When you are looking at the ground, you always have the ground signal; that is your ground speed.

(Simultaneous discussion)

Staton: That comes along for the ride; the problem is getting rid of it.

Bowles: Would moving some of these reference frames eliminate some of these difficulties with respect to ground clutter?

Staton: It is something to be considered, but it doesn't really suddenly ease my mind.

(Background discussion)

Crabill: Will you consider it at this point?

Staton: Well, I always have. In fact, the chart I showed you based on the '82 flight, that chart was originally done only on looking at gradients out there, and not worrying about airspeed. Later, we put it to the ground by using INS to make a chart.

Hildebrand: I had a question about your funding. I guess it's a question for both of you. You just presented a timeline in which your plans for development are closely tied to the FAA plans, and the other part is when you made a presentation of budget, you indicated substantial funding other than FAA funding to your program. Are you presenting simply the portion that is pertinent to the FAA, and if so, are there other portions to the program that we should know about?

Staton: I wasn't prepared to talk about funding, but I can say the schedule there has involved hardware in a flight program that is predicated upon a massive increase of funding from some source.

Bowles: I have that worked out, and we can get back to that.

(Unintelligible discussion)

Hay: Do I have to sit there and look straight down into the ground for the distances that we are talking about that we might need? Do I have to look straight into that clutter to get useful information?

Staton: Most of the action takes place below 2000 feet. As you get closer to the ground you can put a bias on the antenna and it will look a little different, but when you get that close, you already have to have been looking ahead. You can't avoid the significant amount of that clutter.

Bowles: I think the issue here is if we as a group agree on, where is the gaining area, what piece of airspace are we talking about? What we are talking about literally is 4 minutes of time. Somebody is going to deliver me out there around the outer marker under a different set of conditions. What we want is protection between outer marker and threshold. There are certain geometrical, both spatial and temporal, features of these events that may be, could be capitalized on in this detection problem. The boundary layers are 300 meters thick on the outflow. You have demonstrated on your triple Doppler analysis that George may have underestimated the divergence of the ground. You have also demonstrated that the vertical wind may penetrate closely...on initial approach based on the dual Doppler spectrum. Is pulse microwave Doppler the right technology? What about CW aperture defocus at constant distance in front of the airplane?

Staton:...exotic technique, it really involves modulation speed, pulse Doppler is only one, staggered pulse string Doppler is another one, you get into range ambiguity problems. Any number of modulation schemes can be thought of. CW is just one. We are not going to close this effort out, at least as far as the analytical part against any promising scheme. When you go to hardware, you have got to commit to some lesser numbers of schemes than you might otherwise like to have. What we need to do over the next few months is to lay out exactly the kind of hardware we are willing to live with in the program.

Bowles: I guess that gets down to the question--can we write down a set of systems requirements for this?

Staton: We can't do it today, no.

Bowles: I mean, but we ought to come to some set of concepts at least, of what the system requirements are. The British were very effective in demonstrating the milliwatt Lidar looking four seconds in front of the airplane. Four seconds is worth 12 knots of airspeed advantage, given the acceleration of the airplane. That's not trivial. If you give it 20 seconds, I'm really zinging along there. The other point is that a prudent approach to this problem would look at the doppler as a...observation. What the doppler sees t seconds in front of me, the airplane will experience t seconds later, and those estimates, those observations, can be weighted and faded according to ground clutter or not.

(Unintelligible discussion)

Bowles: You proceed under a warning and you elevate it to alert and then you drop the hammer and go.

Schlickenmaier: Is there any way you can scope the eight hours we have, what kind of system environment we are looking at?

Staton: Are you talking about the research radar or for the commercial thing we are looking at?

Schlickenmaier: Well, both. But specifically, the commercial applications. I'd like to tend to focus on that. Is the research effort tied to the live applications? Are we talking about an approach system that is tied strictly to a pitch-hand, one-angle look, 10, 20, 30, 40 seconds in front of the airplane?

Staton: Obviously, we could not live with that, because when the MLS is in place, the flight path will be curved and be tangent to the runway.

Schlickenmaier: Thank you, and Charlie thanks you too. Question: What kind of following are we looking at, in a conceptual phase mode? In the approach mode, are we looking at something that is going to give coverage all the way through takeoff and go around; you know when the pilot hits to go, is the antenna going to go up to best height, or are we still going to have to look out t seconds ahead, or are we strictly looking at a case where it's under 1,000 feet within 5 to 10 miles of the airport?

Staton: You are not really limiting the performance we are looking for for those kinds of cases. We don't really know what the capabilities of the system will be. We will look at all these things and explore the implications of them to see what the bounds on the performance are.

Schlickenmaier: Can we make a definition on what kind of capabilities we are going to be aiming for?

Staton: We are aiming for capabilities that will make takeoff safe. I'm in no position to determine what those physical constraints are. I'm not at this point trying to limit the capabilities of the radar, I'm just trying to see how broad its capabilities are. I don't know what that is.

Schlickenmaier: In other words, can we set up subsets or should we wait? I get from you that we should wait before we set up the performance subsets.

Staton: I feel we have to wait; I'm open though. And there are other people in the room who have ideas on this topic, too.

Hildebrand: Herb, I think the wisdom of going ahead with a straw man set of criteria depends on the use to which that would be put. I'm temperamentally the sort of person who likes to say it should be like this. But, I have also learned through my intuition that at this meeting, we say what we think right now it should be. That's a temperamental response just as much as his response, and I have also learned in the budgetary process at NCAR that if you do that at a wrong time, some jerk will write it down and in 18 months' time come back and say, "But you said...," and you know I realize that, and I don't know the political waters here, and I think you gentlemen have to figure if it's safe enough to do something like that. We certainly can come up with a best guess.

Schlickenmaier: I'm not looking for best guess, and maybe it's my temperament that I like to have multiple...What I'd like to see are a number of scenarios that we might be able to address strictly from a talking point of view, and what I'm asking is whether we are at that point yet, whether we can set up a set, you know, looking at both takeoff and landing.

Staton: We certainly could do that, but I think we could do that in a day and a half. But if you are going to conduct a program, you've got to decide what path you are going to follow. You can not follow all possible alternatives. I have no problem with writing down all kinds of possible alternatives, and maybe the choice could be made to direct our efforts, but...

Schlickenmaier: Do you think it would be worth it in terms of scoping what possible systems, possible futures, do you think that exercise would work, in the embryonic technology stage? And just be open to a number of issues?

Staton: It's always presumptuous to say that there are not ideas with which you can look at a problem. We have been looking at this problem now for about a year and I don't see too many alternatives to the approach that said what we're going to do when we get to work next Monday as to what we are going to do. So, we can talk about various possible future realizations of this radar, but they wouldn't really have a lot of impact on what we do next Monday.

Schlickenmaier: I'm open for other people's suggestions on this topic.

Unidentified: Leo, can you summarize briefly where you think the breakthroughs are needed? In other words, I get the sense that this is really a single processing problem, not a radar hardware problem. Are you up against some limit with solid state amplifiers, power amplifiers, or are you up against some time limit?

Staton: Yes, I'm glad you brought that up. The trend has been toward longer pulse length and lower power in airborne weather radar. We are talking about a throwback in a way. We need more resolution, we need, if we stick with pulse Doppler, we need shorter pulses. In any case, we need shorter bandwidth, because we have got to resolve smaller cells. So that's going to drive the power back up and may throw us completely out of the solid state transmitter regime, at least for the next few years. Ultimately, we'll catch up with whatever we need. We are talking about a throwback, a trend in airborne radar. But I would see that as a fundamental problem. People don't know how to deal with tubes. We haven't built them for years. Radar hardware itself is not the problem. It's processing and what parameters you are going to impose on it.

Unidentified: What about operating at frequencies that will give you a reasonably sized disk to put on the front of the airplane? Are there any physical limitations or problems?

Staton: I don't really think so. There's a problem in that you have to work at dual mode; you are going to have to stay down at X-band for the en route portion of your approach. If you want to switch frequencies and you want to be able to do that all in the same unit, that's possibly a problem, but there're ways to use a waveguide array; the radiator in one case was the reflector for another feed--all kinds of ways you could implement a dual frequency approach if it came to that. I don't think radar technology as such is a big problem. It's just putting together sets of parameters on the radar and handling the signals--making them work against this kind of environment. Radar technology will blow your mind. There's big ground-based radar that can trace many, many targets simultaneously while scanning. We are not pushing radar technology. We are pushing airborne weather radar applications and the signal processing for the clutter suppression. It's a formidable problem. It just may turn out to be as bad as I think it is some months down the road when we go through some of these ground clutter analyses, or it just may not be as bad as I think.

Hildebrand: Well, I think there's an area of radar technology that is very much a part of the problem, and that's the antenna radome. The extent to which you can solve your ground clutter problem is directly related to the amount of money you spent on the intended radome and the quality of the beam pattern you get outside the radome. You have to realize this is a problem when you look at the innovative designs people paint across their radomes. The relatively little concern about what really comes through, and if you look at a military radome, it's always painted a very limited spectrum of colors, because it makes paint difficult and expensive. You go into exotic shapes and designs, for another thing.

Staton: Yes, the shapes we're dealing with on airlines are fairly smooth, I don't really see where design is...

Hildebrand: Yeah, well, on the other hand, you look at the size of the room that has been allotted for an antenna in an airliner, and the size of that body, and you realize that relatively little attention has been paid to the problem of designing a really good radar. There's a lot of room to move technology to build a substantially better radar. It's like building your home stereo; it's the speaker that matters and money pays. It's a direct cause and effect relationship there. Put up an AWACS antenna and you are going to be able to resolve that microburst, but you can't afford it. And, I think there's a central problem here. If you are really going to do the job well, very high performance radomes and antennas are going to have to be built in. Volume production is going to have to be used to drive the costs down to an affordable level. For our research radar that I'll describe, we are talking about antennas alone that are going to cost on the order of $150,000 apiece, after engineering costs. And we have that from enough independent sources to be pretty much convinced that it's right. You can't afford to put that on an airliner.

Staton: That tailsting radome on the P3 cost us $40,000 in 1976, and that was a ripoff!

Hildebrand: I think those kinds of problems, that's an area in particular where there's a technological problem that has to be addressed, and could have a big effect on solutions. Most of the rest of the problem, I agree, is old hat--simply application and algorithm stuff, that's technology tools.

I will give a short presentation of the NCAR airborne Doppler development program. I will start off with a little story that tells you something about why I'm interested in this. John McCarthy has been encouraging me to be practical in things for a long time. When you send your kids off to visit their grandparents, and you go to the airport, and they are flying in and there are rain showers, you begin to think a little bit more about devoting effort toward the practical problem rather than just working on the research problems. And then I recently learned that a friend of mine, who is a professor at MIT, had been scheduled to go on the airplane of the young lady that went to Russia after she wrote to Andropov that he was a warmongering Communist, or whatever she said, and then he invited her to visit Russia. Well, this friend of mine was scheduled to get on that airplane. He went to the airport, then he looked at the sky, and didn't like the weather. He looked at the airline and he decided, well, this is not an airline that is high-tech in terms of weather training, so I'm not going to get on the airplane. I don't know of anybody else with training in weather that has ever made that decision. I have never made that decision. Has anybody here ever made that decision? One person. It takes a lot of courage to do that. Most of us place our trust in pilots and all of us here are in a position to know what kind of quality sensors that pilots have in front of them. We all know that the combination of sensors and training and pilot tiredness and all that isn't optimal. Yet, we always get on the airplane. All that makes me want to try not only to devise a better research radar, but to apply the knowledge we gain in building that radar to the task that we are discussing here today. I think that one of the very important things that I have come to believe is that the radar that I will describe can be a valuable development tool in the path to getting to better air transport type radar.

I want to describe the NCAR Electra Doppler Radar. One design constraint we are facing is we are not going to buy a new big airplane, we like just what we have. The person on the staff who's good at names came up with this. This is the cover of a document which describes our design plan. Within a couple of months, the draft will be suitable for handing out, probably as a technical report. Our development process has been a multifaceted process, and I want to give you a little overview of that. What I will describe is the development process, the specification of goals that we are trying to design for, give you a feeling for the goals we are designing for, then how we intend to design the radar. This is a sort of a flow chart I drew. It shows a lot of the features that are going into the design of our radar, and I don't suspect it is a lot different from other radars. We have needs for radar and the needs describe measurement goals, sensitivity, spatial resolution, temporal resolution of the data you are going to get. These goals have an impact on the technology you are going to need, and once you decide what you are going to measure, you have to find out, can you measure it? Are we using existing technology, or are we going to design something new? You get a bunch of design options based on different technological possibilities, such as difference in wavelength, antenna, beam width, or sidelobes or other things like that. As I said, we have to use the Electra unless we want to use some small airplane, which didn't seem like a good idea. So, we put all these things together and we came up with a preliminary design plan based on technology and goals--some constraints, including dollars. Other inputs to the design plan come from some sort of prototyping phase, and for us the prototyping phase involved using the NOAA P3 airborne Doppler radar system. We realized that it was a lot easier to do our prototyping using somebody else's radar. At the time we decided this, the radar was not functional; it had been built, but as a Doppler radar, had never been made to work. So our senior engineer and I went and fixed the radar and we designed the flight test program, and we carried out the program through a couple of iterations, the last being the JAWS project. The numbers over here are rough years. It tells you something about the length of time involved between collecting data in 1982 in JAWS and finally publishing some papers in a publication. The two papers will come out in the September issue of The Journal of Atmospheric and Oceanographic Technology, this month's issue, probably be coming out next month, that I authored with another person describing these tests. For one, the evaluation of the collected data set, which is an important part of the prototyping process, is very slow. It goes into the design plans and tells you a lot about how to do it and how to not do it. You get to a plan and then you have to figure out, is there a link here that makes any sense at all? You go back and you revise, on new information. You compare the resources such as the dollars, the good-will of your administrators, staffing restraints, and again you revise until you have a realistic plan to build. Finally, you are at a step where we have a design plan for the radar that I will describe to you. You are well aware that any like this will go through a whole bunch of other tests and steps which get less and less specific as you go along in the future, and I don't know what's going to happen. We have a plan where we had a design review where we brought in lots of meteorologists, engineers who are familiar with meteorological research Doppler radar, and we have them take their best shots at our plan. We are having to make some revisions and we'll come up with a final design plan which will be available in a month or two. We are now beginning to get into some preliminary component tests for the radar. Based on these two items, we will make decisions about what we send out with our fees or do in-house construction on and start the flight test, etc. These are difficult steps, but when we finally get to flight testing, we will have to have developed all data analysis algorithms in such a way that we can produce a radar that has been tested a year later. Which means that we will be doing our research evaluation a lot faster than we normally do a system.

Unidentified: Have you selected a carrier frequency yet?

Hildebrand: Yes, it's an X-band radar. Our first step in all of this was to figure out what kind of radar we wanted to build, what do the users want to measure? So, we went out to the community and we asked the people what the community needs for radar work--what kind of research project you want studied, mesoscale convective stuff, squall lines, hurricanes, what kind of design goals are necessary, spatial resolution, temporal resolution, etc. We sent out a hundred questionnaires. We basically took an old radar conference and selected a bunch of names and sent it out and got almost half of them back, and according to my sociologist friends, it was a fairly good response to a questionnaire. The questions we asked, we asked each person to specify what they wanted for their research, and we did our best to tell everyone not to tell us what the community needs. We asked what plans you want and what are the resolution measurement accuracy and sensitivity and aircraft characteristics you need for the radar and you want to use in your research. Some people gave us some very wise and thoughtful answers and some people didn't. Here are the results of the little popularity contest. Mesoscale convective complexes came in number one, although we don't understand how those things work--thunderstorms that are hundreds of kilometers or states across, and nobody really understands how they work. Although I asked people to give me pictures of them, they would give me a couple of pictures, and tell me how their recollection is something different. So, I know that people don't really know what they look like all that well. Severe storms are right up there in the popularity contest. A lot of other things, but of particular interest are hurricanes and ocean storms you can't study with ground-based systems. In terms of resolution requirements--by resolution here, I don't mean resolution of an oscillation or wavelength resolution, I mean data density. How often do you need to make a measurement? In the vertical, people thought we needed to make measurements every hundred meters to four hundred meters, depending on the feature being looked at, but small cumulus scale people thought we needed to look at hundred-meter resolution, both in the vertical and the horizontal. People looking at severe storms see these 200-and-something meters (these are average mean values) vs. 300 meters. Microbursts are in this range. You can't afford to have one-kilometer resolution and even hope to measure microbursts. It just won't cut it. The time scale--the cumulus people thought we had to have a measurement every minute. People studying CB's weren't a whole lot more forgiving; they said about every three minutes. What we know about microbursts says it's going to be more like a shorter scale than a longer scale. Five minutes is a long time in the life of a microburst. We asked people about the domain size they wanted to look at. The hurricane people wanted to have a domain horizontal extent approaching 200 kilometers. The small cumulus people only needed to look at 15 or so. That's probably the kind of scale that we're talking about. But people also realized that with an airborne system, if you need to see 200 kilometers, you don't have to see it all at once because the airplane moves around. So they realize that the radar range can be a lot smaller. The hurricane people have more experience with airborne Doppler radar, because they have one. They realize that if you can look 60 or 70 kilometers, you are doing fine.

Crabill: You say they have just one airborne Doppler radar?

Hildebrand: Yes, one on a NOAA P3. Just one airborne Doppler radar.

Crabill: Your vertical scale confuses me. It says horizontal range. On the lower...

Hildebrand: This is horizontal range, horizontal domain size. I'm showing they realized that you can move your domain around and thereby encompass a large measurement domain. So that the hurricane people, although they need to see 200 kilometers, only need a radar that puts out 60. That's the nice thing about the airborne Doppler radar for the job of a microburst. You move the observational domain to where it matters.

In terms of radar sensitivity, people wanting to look at small cumulus clouds thought they had to be able to see about minus 80 dBZ out to the maximum range in which they were interested. That's a pretty sensitive radar, but it's not a tremendously sensititve radar. We think you have to measure more accurately than that.

Unidentified: Maybe I'm ignorant, but what is Z value?

Hildebrand: It's millimeters to the 6th per meter cubed. It's a meteorological unit that relates to liquid water content in a really cloudy situation. The normal meteorological unit is reflectivity in Z units, or dBZ. It turns out that this kind of requirement here is roughly zero at 30 kilometers or more, is a much more stringent requirement than this. It will more than meet these goals. I will show you sensitivity calculations which we've done. In terms of measurement accuracy, lots of people show lots of lack of understanding of how likely you are to measure reflectivity in an absolute scale. I don't know of any radar that is calibrated well enough to give you one dB absolute accuracy. Relative differences, sure. The velocity accuracy people want about half a meter per second, that we can achieve with the airborne system. We've shown that with the NOAA P3. The last one of these charts I will show you is something that is helping us to design the radar a whole lot. I realized that all these requirements were tied together and when you look at the large domain, you need low resolution. In fact that's how radars are being built, if you want to look at a large range then pulse length is usually increased. So, as the resolution needs go up, the domain size gets larger, the time scale gets longer, the vertical resolution gets longer, and you can design your radar to zoom in effective ways. We will try to do this in a way that zooms at the rate in which you scan. So, if you are looking at a small area, you look through fast, you look through it with high resolution, but you don't look very far. And if you want to look at a very large area, you scan more slowly, you get coarser resolution and spend more time, but you see a lot more. It fits meteorological phenomena and again microbursts are going to be in the short end, high resolution stage, but, I think there's no reason why they couldn't be done with the same radar that does the surveillance job. It's a matter of designing it to do both things. We described, using our user surveys, measurement, and scientific research goals and then thereby government criteria and came up with some design goals. The available hardware on the aircraft have another input and we also put together a design philosophy. There are some constraints on what you have to do with the airplane to collect useable data or how you design the system to provide reasonable displays that are very important and similar. You've spoken of, for example, the idea that you can't display the vector wind field to the pilot and expect him to look at it or use it. Well, my experience is it is very hard to display Doppler radar data to scientists and get them to look at it. During the COPE experiment (the Cooperative Convective Precipitational Experiments in Montana), horrible name, but a very interesting experiment involving the Bureau of Reclamation, NSF, the NASA CV990 and other aircraft including a NASA B-57, I used to go into the operations center and tease the operations director by quietly turning the displays from reflectivity to velocity. None of the people who have sufficient stature to have the exalted title of Operations Director had any interest in looking at Doppler velocity. They all wanted to look at reflectivity. They could understand the series of concentric rings, and they didn't want to spend a half day or less that it took to figure out what the velocities mean, even though it's really simple. If they made it through calculus they should have been able to understand Doppler. They didn't want to. They're complicated displays, and that's a problem. What I'm saying is, it's not a whole lot different with trying to get a pilot to look at something and a lot of scientists.

We need the radar to operate relatively automatically given some very simple inputs. We want to ask the scientists running this thing, what is the resolution you want out there, or what is the domain you want to look over? Just one or two questions. You have a radar to decide everything. We want to have displays that operate in a fast intuitive manner. We want people to want to look at them. We don't want our operations directors in the air to be turning them off, and they will. We want to correct for typical Doppler radar problems such as folding and sidelobes as much as practical as you can write a dollar sign in there. We want the radar to be designed for expansion improvement, we have to do that, or we can't afford to build the final system. We want the system to be reliable and easy to maintain in the field. The frequency choice is based on many considerations. We want to fill up space with radar observations. We don't want a lot of measurements over here, then a big gap, then a few more here. We want to uniformly fill up that convective cloud with observation points. We want to have an adequate level of range and velocity measurements or minimize the ambiguity of the folding range or the velocity to the point that we can handle the data. If the unambiguous velocity range is plus or minus 5 meters per second in a severe storm, we are just not going to solve the problem. I can attest to that. It's been run on me, and I couldn't solve it, and other scientists and engineers could not reliably unfold the data. Based on these kinds of considerations, we can come up with some recommended ways. The other considerations of the design relate to sampling goals and filling up space properly, and that has implications to how you scan. There are some sampling rate considerations that have other implications for design that tell us we are going to need multiple frequencies. I'll mention those issues shortly.

Radar scanning and data collection are 1) quasi-evenly spaced data. 2) We need adequate spatial resolution, scientists tell us how often we have to take measurements. If you want to look at a microburst, I think you have to have a measurement under every few hundred meters. 3) Minimize the length of time it takes to scan through the volume of interest to measure the phenomenon you want to measure. 4) You want to require the airplane not to do something strange in the air and in our case, we have the problem of a big meso-scale squall line that goes from Oklahoma all the way across Kansas, say. There are high reflectivity level five or red, or whatever you want to use, areas in there. You flat just want to fly through that. If your flight track requires that you fly L-shaped patterns, and look inside the corners of the L's, you can't take measurements of that storm. We have to fly straight lines past the storm. 5) We want to be able to mix airborne and ground-based Doppler data and, 6) we want to have the potential for a near real time for an analysis for the data on the airplane. It turns out that if you can see what you are measuring, you can do a better job. Well, the P3 tests helped us a lot to evaluate how to design this radar. In the JAWS experiment, and this is taken from one of two papers from that, there are two ground-based radars, the CV2 and CV4 radars, that observe the storm within a 20 km x 20 km box. The P3 flew along the flight path and there are a number of different dual-Doppler analyses performed. Basically, understand what we try to do in our scientific analyses. If you have a point in a storm and you want to know what the horizontal velocity field vector is at that point, you need to observe that point from two locations which are different. For instance, if you observe from here, you can get the component of motion along that line. If you observe from here, you have got motion along this line and from that you can calculate the east wind or the north or whatever horizontal wind you want. Similarly, from the two ground-based radars, even though they are not orthogonal, you can still do a good job of analyzing the wind field. So, we did a comparative analysis scientists are familiar with, taking two ground-based radars in a storm in this geometry and calculating the wind field. We also calculated wind field using this flight track and this flight track, or this one and this one. We compared those analyses with these analyses.

Staton: How does the time difference between the airplane measurements affect data?

Hildebrand: The airplane data are collected over a period of seven minutes from the beginning of this to the end of that. The actual data review which we used was over about 5 minutes and for the large-scale storm feed structure, those differences don't amount to a whole lot. The effects of those time changes are discussed in the paper.

Staton: The reason I bring it up is that Norm did some work with the F106 comparing this ground-based Doppler in Norman, Oklahoma, to another. A few minutes' separation in run made a big difference in comparison between the in situ winds and the ground radar.

Hildebrand: Yes, but remember, when you are flying an airplane through a storm, you are literally drilling a very narrow hole through that storm, and the difference he observed may have been the fact that that hole got advected over here when he flew through again, and he was still down here. With radar, we can measure the overall flow field. In fact, we can adapt one with respect to the other, and find that they are co-located. We did that, and over this length of time, there really is not a whole lot of change. It's enough to worry about, but it's not so bad you can't do this job. The bottom line here was that the effect of evolution and advection was smaller than analysis generated areas, purely a numerical analysis decision.

Here's a comparison of the airborne (which is the lower panel) and the ground-based analysis. This is one cut through a convective storm. Let's look at the ground-based analysis here. Here's the high reflectivity region, here with a downdraft coming down to the surface. The weak echo region inflow is shown here, and the updraft here and outflow. This happens to be an east-west cross section, the reflectivity contours show the formation of the anvil off to the back of the storm. This is 20 kilometers across here, and the height goes from 0.6 kilometers above the surface to 13.6 kilometers altitude. A fairly difficult cut through a convective storm.

Unidentified: Where was the airplane with respect to the...?

Hildebrand: Well, the lower set of data we collected with the aircraft, and the airplane was flying basically along here. This is the aircraft analysis. The horizontal wind measurements are within a meter per second or so throughout the measurement. The only area where there's a large difference is in the vertical velocity component only in this area here. The reason that there was a large difference there is that you have winds blowing straight into a high-reflectivity area. Doesn't make any meteorological sense. This high-reflectivity area is an obstacle the way the environmental air reacts to a storm as if it's a post in a stream and the air goes around it. Well, the air goes around the storm. That's the way the storm works. The air is not going into the storm like that, it's getting entrained and then going up over the top, and around the sides. So this is wrong. The reason that it's wrong is that the sidelobes, the antenna on the P3 is a fairly lousy antenna. With the technology available at the time it was built, it was a fantastic job, well-built and designed antenna, but it's just not that good, it's been hanging around over the years. It's got sidelobe problems and looking at a high reflectivity gradient and a high velocity gradient and what it was seeing here in the low-reflectivity area reflected a lot more what was going on here in a high-reflectivity, higher-velocity area than what was really happening, and I had to edit those data out, out of the single Doppler data, out of the individual scan from the airborne radar before I did this analysis, so that there were no data at the top of the storm. I correctly perceived that there was a problem with the raw data. Consequently, we didn't have any measurements from the top of the storm and the importance of that is that the way we do our analyses is we basically calculate all the horizontal wind and then you look at some boundary, like the top of the storm and you assume that there's no vertical velocity up there. So, if you've got flow like this and you get to the top of the storm where there's no flow, you know this flow is going to be going out. That just makes sense. Well, from the radar point of view, you don't see this because you are looking at it sideways. What you see is a diversionary object. What you assume is zero vertical velocity above it, and you put these measurements together and you can deduce that there is a positive velocity there. There just has to be some continuity. You didn't create that air, and the only place it can go is up. And it turns out what we did in that particular case was, I had thrown all that stuff out. So, I had thrown out the boundary condition to show that there was a vertical velocity there. Therefore, in that part of the storm we lost the vertical yet we still correctly measured the horizontal. Now what impact did that have on the analysis, on the development of our radar? It tells us that we have to spend all the money we can afford to spend on the quality of the beam pattern outside the radome. We are trying to design for on the order of 30 to 35 dB per sidelobe outside of the antenna. What we need to do there is push antenna design technology as hard as we can afford to, and radome design technology and see where the price performance curve starts to change, and they do. This is a problem that is very similar for the systems for wind shear technology. Let me back up a little. Can go up to 70 dB on an AWACS antenna, but we can't afford it, and yet if the technicians start to touch it, we don't have it anyway, so there's no point in going there. 20 dB isn't really going to cut it too well. The comparison was that we were very happy. We saw that the airborne systems made measurements that were very much like the ground-based system and the differences between the measurements were more attributable to problems like that upper boundary condition like where you assume zero or should you assume zero or how did you filter the data that was collected in radial space and how did you filter that and put it onto a Cartesian grid for analysis? Those are analysis problems, and are tough problems, and those are worse problems than the fact that you're using an airborne radar. It says it's an okay tool to use and we're charging ahead because of that. And I think it's a good tool to use to measure microbursts. Let me tell you a little bit more about the NOAA P3 radar system. Basically, it's in the tail of the aircraft. It sticks out of the back of the aircraft and spins around like this as it flies through the air and in the length of time it spins around like this the aircraft moves some distance that is determined by the scan rate and the aircraft's true airspeed. And because of all that, you can then define the data density. The data density goes one measurement here and one here, you've got pulse length, density here and scan length. We just have to adjust all these things. In the NOAA P3 system, in order to make our measurements inside of the storm, we make measurements when we fly here and when flying down this track, we make measurements on this line and this line. And there are intersections where we can get our two-dimensional wind field. The technique we are going to use uses two antennas on one airplane. One other thing that I want to mention is that we think that the pointing angle measurements from the antenna are very important. We can define the need of certain conversions, the ability to measure convergence at the top of the storm. That translates directly to the vertical velocity accuracy, and there are scientific needs for certain accuracies, etc. We can turn that into a velocity measurement accuracy and we have been able to do the same sort of thing for the microbursts. In order to get half a meter per second (I'm not sure this is the right number, I made these numbers up a couple nights before I gave the talk), we think that we have to make measurements to better than 3 tenths of a degree of the antenna pointing angle. We have to measure the difference in the antenna pointing angle and the true airspeed vector. The airplane's flying along in some direction and the antenna is pointing out there. And that airspeed is getting to the radial velocity measurement. Taking those, we can measure the aircraft airspeed with some accuracy and let's assume that's perfectly accurate, (of course that's really wrong). You can then describe the accuracy in antenna pointing angle where it is necessary to measure the radial velocity measurements accurately for these purposes. And it turns out that we are getting down to accuracies that are pushing the state of the art to point something from the airplane and we know absolutely where it is. I don't think this is as bad a problem for the wind shear detection radar, and I think you can get away with looking at derivatives. You can detect where the ground clutter is. So, we are going to design a radar that on the airplane at one spot has one beam that looks back, and another beam which looks forward. So, it slides along and at every location looks both back and forth. If you scanned the whole surface around this line here you fill up space with this kind of ring here. So, we will have achieved our goal of making measurements relatively equally with the exception of in the elevation angle, these things will get more coarse. We will be able to change the resolution from about 150 meters to out to a kilometer, either in this direction or in the other direction, just by changing the pulse length. We can look over domains like this. It will take us on the order of (on the average) of under a minute to six minutes to sample.

Here's a picture of how the scanning goes. This is much simpler, the airplane flies along this line with one beam looking forward and the other one aft. They both spin about this axis, which is roughly the aircraft centerline. Actually you want the aircraft to be parallel to the ground, so you have to figure out the pitch angle for some nominal loading and altitude, and airspeed.

Unidentified: Do you have both phased arrays attached to the same panel?

Hildebrand: Yes, basically. I'll get to that in just a minute. Now we run into a couple of problems. One of the problems has to do with how fast we have to scan the antenna. If we are going to scan it around so fast that we get back to the same elevation angle in 150 meters (that's the speed of the Electra), we have to scan awfully fast. It turns out that we have only 3.5 milliseconds to scan that far or about 7 if we scan every 300 meters. We can relate to the time of independent sampling and that is due to particle shuffling in the atmosphere, and that is related to the turbulence intensity and the wavelength. Basically, a particle has to move certain distances with respect to the wavelength in order to be a statistically independent sample. You need to do some reshuffling. Virtually everything that we are going to look at is. Well, we think we are going to end up with a 3-centimeter radar. The sum amount of turbulence, there's turbu lence here and here; it says that there are some cases here where we're in the last turbulent areas such as stratoform clouds, where we will have trouble getting independent samples in the length of time we have available to collect, so we need to go with some extra tricks. Sample in elevation to solve the problem and there are a couple types of things we can do.

Staton: What you are really saying is that the Doppler bandwidth is such that this is the correlation time of the process. Why is that important?

Hildebrand: The problem is that you want a sample population and you are not going to sample the whole population, you have to sample it a certain number of times.

Staton: If you sample it at times more infrequently than that, you don't get Doppler information.

Hildebrand: We get Doppler information on every sample, but the trouble is that Doppler information itself is just a sample of the true. And you need to make several samples of the Doppler information on a distributed target. Remember this is a distributed target; you can't use a point target radar carrier. You have to get several samples, average them together and come to an estimate of the mean radial velocity in that point. We figured out that we are going to have trouble there, so as your radar looks out within some beam, you have some length of time, number of pulses, and we are saying that our assessment of the theory is that we don't really have enough time if we just transmit on one frequency--and that with the one pulse in that length of time it is difficult to get a good estimate of the mean velocity. There are a couple of things we can do. One is we subsection the pulse in two halves. You can average those two together. Those two are independent. We just doubled it. Another thing we can do is instead of just transmitting on one frequency, we can have f2, f3 or f4. Obviously, now we can get up to say with f4, eight samples here, two in range and four in frequency and you just raise the complexity of your radar. Well, we are working on those problems, but it is an area where we are having to push pretty hard. The bottom line for the proposed set of specifications for the radar is that it will be an X-band radar, it will have up to four different transmitter frequencies, all in the same transmitter. The beam width will be about 1.8 degrees. Peak power will be about 100 kw to the transmitter, which is 50 kw per beam; the average power about 250 watts per beam, pulse width variable to between 10 to about two microseconds, and these limitations are a result of limitations on the tube. PRF available in about this range here and a sensitivity of about 0 dBZ at about 25 kilometers. That's on the order of 10 to 20 dB more sensitive than the typical surveillance radar. The layout on the Electra is very similar to that on the NOAA P3. All the antennas will go to what's called the rotodome, with the antenna and the radome all working together. RT unit will go back here, and because the aircraft flexes, the airframe bends an appreciable fraction of a degree, so we put a separate INS back here. Now the data system is somewhat forward over the wings, and is probably more forward than this, just to maintain the weight balance where it ought to be. Now the concept for the antenna is as follows. Everything aft of this line will rotate together. These will be fixed antennas, they will not be stabilized at all. The only motion of the antenna will be the motion of the roll axis which will be driven in such a way as to be inertially as decoupled as possible from the airplane's main pitching motion, so that as little aircraft motion as possible is transmitted to the antenna.

The antennas, we think, are flat plates with slotted waveguides. They will be fixed within the radome. There is some proposal for mounting one pointing this way and another pointing that way. We are looking into that. It will be pointed 30 degrees forward and to the normal of that. The advantage to having the radome rotate with the antenna is that in designing the radome, you only have to deal with one beam position. That should be a lot cheaper to deal with sidelobes. We're also thinking of using inflatable radomes. The whole thing will be mounted on the back of the Electra and will probably be removable in a way similar to this and could possibly be mounted on another aircraft. It's a system designed for change and certainly designed for possible mounting on another aircraft. We are right now talking about two radars, and that's a matter of some faith. I have a red radar and a blue radar. I presume we will come up with more exciting names. But that involves two RT units, each one having some spectrum of frequencies to transmit, each having waveguide out through some very complicated apparatus, like rotary joints. We'll have pulse-pair processors for each frequency. Possibly some sort of scheme for unfolding the velocities and then transmit out to the display and then to some recording capability. We would record the I&Q output here, before processing, with the ability to go back and change how we did things. But, I think what's more likely is we will record the output of all the pulse-pair processors, from all receivers. We still have a lot of ability to go back. It won't only be when we have really figured out to do the unfolding job--again, the unfolding job, a pretty tough job, in fact it is tougher than the typical military point target unfolding job, which is something that is done with some accuracy as a matter of some routine. That's where we would like to get to, because the data recorded density goes way, way, way down and lets you do that. The current estimated bottom line in terms of radar sensitivity is shown here. There are three wavelengths to consider. This shows a 2-microsecond pulse and includes the effects of atmospheric gaseous attenuation. This one also includes continua- tion due to hydrometeors estimated at a quarter gram per cubic meter of rain. This illustrates why we want to go to X-band in the field. Particularly considering that severe storms...The X-band system here, if I remember right is on the order of 15 to 20 dB more sensitive than the typical commercial radar...My guess is that we need something in between the two in order to do the microburst problem. We are getting specifications from jobs people about what reflectivities they think they need to do a decent job. Somehow they haven't really come to grips with that problem yet.

Unidentified: How do you think the clutter problem will be handled?

Hildebrand: Clutter is certainly a problem in that we have not evaluated the combined effects of clutter and its effects on low signal. It is certainly a problem on the P3. You can look out and, here's the ground and the airplane's up here and maybe look down and see a microburst there...a little higher up, but you can see something else. You can see this ring all the way around the airplane, that's the range to the ground. Probably have to live with it. The observations I have for the P3 show measurements down to within a few range gates of the ground.

Unidentified: How do you take into account the motion of the aircraft?

Hildebrand: In this particular case, the antenna was moving right along and the aircraft was flying level, the antenna is constrained to move right along the ground. Talking about an angle, you subtract it out. I know the aircraft's velocity within 1 m/s or so, from the INS. Then do a little vector addition for each beam. I add on one and I subtract on the other. You can use the radar with four beams looking at the ground and actually measure the velocity of the aircraft, but I don't think we really need to do that at this point. As soon as GPS is available on board the airplane and we'll know the aircraft velocity a lot better than necessary. We have already tested it on the P3 and we are able to remove the aircraft velocity well enough with the antenna pointed 15 degrees forward of normal to stop the ground. In the data, once you've stopped the ground you know you've done your calculations correctly.

Bowles: It looks like you are putting together an excellent radar for atmospheric research, and that's where the program is initially going forward to, according to the survey that you cite. How do you see the applicability of this radar to a full...wind shear detector?

Hildebrand: Well, I think it is quite applicable. I don't think that it matters a whole lot whether you are within five degrees forward of normal, with the airplane going straight forward. Getting the aircraft velocity out of the data is just as bad. I think that's just one problem, but there's only 120 degrees dead zone ahead of the airplane the way you've got it set now. I'm not trying to look ahead of the airplane and do wind shear avoidance with this. I'm trying to fly past phenomena and measure them. Now I would submit that those problems are really the same. That the only difference is when you collect the data and how you decide to use it and that is an operational problem. But the problem of making a measurement of phenomena doesn't matter whether you happen to be looking forward or looking out the side to see them. If I can measure that phenomenon with my radar, I can describe how you then measure the forward information.

Bowles: The accuracy, the constraint which you place on the radar with meteorological research may place a very severe constraint on the design of your radar. It may not be there, but the device is purely trying to detect a certain climatological...

Hildebrand: In fact, I think that what the advantage of this whole system is to those of you interested in detecting wind shear is that we'll have this thing available and we'll be able to measure the wind shear phenomena and describe what you would get if you operated your radar in thus and such a mode. You wanted to change the elevation and put in the angular resolution in some way, you want to change how you process the data, I think we would be able to simulate that. We'd be able to change the horizontal resolution, the radial resolution, through averaging the effective beam width of the radar, the sensitivity. I don't think we are going to have to design a radar that's this sensitive and this flexible to do the job. I think you are going to use very simple derived displays. I think the area where we might get into the same level of problem is in the antenna quality considerations and certainly, adaptation to ground clutter noise.

Unidentified: Let's see how we understand you'll deal with ground clutter.

Hildebrand: I don't know how to deal with it. The only way I know how to deal with ground clutter right now is a twofold approach. One is to build the best antenna you can build and that would reduce the problem consid erably, and that says you are looking at what you think you are looking at. The second is to go to a spectral analysis approach, we need more ability to get at the actual ground clutter vs. meteorological signals. There's some discrimination within the data with each pulse length. And there's certainly been good progress there. If you look at the military application, you see that most of that work is done in the...If you look at meteorological applications, again, most ground clutter suppression is done in a spectral analysis type of domain.

One other thing I wanted to mention is the data processing flaws. This is a horrible collection of computer...Basically, you've got a pulse-pair processor here, that feeds in the data to some housekeeping processor. Now all these are analogs or things that we build, and we are all familiar with them. The problem though, is you have to build your display processor in such a way that it will display the data very simply and interpretably to use it. I think it would also, for the purposes of air safety, be worth having some last few scans available on the flight data recorder, but that may be asking a lot. I think the display processor is something that really needs to be worked on hard and something that we are going to work on hard. We are already getting complaints in advance of the displays scientists are afraid we are going to show them. The other place where work needs to be done is the design of the processing control scan, antenna position, etc. We want to take those decisions out of the scientists' hands. We want to ask them some questions that matter rather than asking them what angle they want to look at. Generally, I think to allow the pilot to uniformly select the antenna tilt in an operational air transport radar is ridiculous. I think we can build a better system that can do better than most pilots do, and they're talking about that. They have quite a variety of ideas and some of them will even remember how to run the antenna tilt...but those kinds of problems are the problems we will be working on, and I think we will have some direct applicability on how you can design...That's what we are working on. It's a project, that in a time of some budget crunch, is funded well enough to do all the planning, and this isn't cheap. We are funded through '86 and we will then be ready to order the major components. I'm working right now on getting commitments out of NCAR and NSF for the funding of hardware, but I don't have the money committed yet. I have the good wishes of the director of NCAR and I think...some support from the division director, who will fund it to the level that he can. Frankly, I'm going to be out there looking for funds and looking for ways I can support other projects.

Bowles: Could you go back to your sensitivity figure? Could you take a stab at what you think the sensitivity needs to be for low-altitude (under 2000 feet) microburst detection in light rain?

Hildebrand: Well, you can see that light rain doesn't have much effect on the signal. I think we are talking about not very far out, maybe 40 seconds, and I think somewhere in the range of 15 or 20, probably. If you want much below 20, you are probably asking a lot. So, I think we need maybe another 10 dB, maybe 15.

Bowles: That sounds about right, based on some stuff...

Staton: What is that you're talking about, dBZ or what?

Hildebrand: dBZ, at a range of 5 km, or something like that. It's a pretty sensitive radar, and it gets more stringent when you realize that you also want as good resolution in range. You don't want 1-mile resolution.

Unidentified: That's based on your meteorological research, though.

Hildebrand: Well, I'm trying to answer for the microburst research by saying it's not a whole lot less stringent than this for the detection of microburst in the weak echo regions...Now for voice regions, you could probably get away with something like 15 dB less...Now in terms of the Collins system, at long range it has pretty good sensitivity, but as soon as you switch the range down to a shorter range to shorten up to get better range resolution, the pulse, you jump up there and it comes down, you jump up and it comes down, you jump up and it comes down like this. You never really get much below zero, in fact you look at it, you see that it's very cleverly designed to always be a little bit more sensitive than the minimum contour they want to show. They are not wasting anything. It is well designed to meet the criteria for the system. And the older systems tend to be designed a little bit less than that, they tend to not have as much pulse length.

Bowles: Based on your experience, what do you consider the probability of success in designing the wind shear detection range system based on your airborne radar...

Hildebrand: I think we might do it.

Staton: It seems to me that most of the problems for the wind shear problem as such, are not really addressed by your radar. If you are going to do any kind of clutter analysis, the only way you could do it is the pulse-pair processor with the time domain filter ahead of it, and once you've gone through your pulse-pair processor, the game is over as far as getting rid of the clutter. If you leave the clutter in there, it's going to bias your estimate when the clutter is in your field of vision.

Hildebrand: If you're speaking of the radar, I totally disagree. We intend, as part of our design effort, to have some spectral analysis capabilities, I think we need that just to understand what we are getting out of the pulse pair processor.

Staton: I didn't see it on your chart.

Hildebrand: I know, but it exists as a design analysis, it's not what we are going to deliver to the scientists, because most of them don't want it anyway. I think that the sensitivity and the resolution requirements that we are going to need will exceed what's necessary, resolution requirements that we are going to need will exceed what's necessary here, but I'm not trying to sell my radar as what you need to build for your system. As soon as we start going at the speed I hope we do, it should be available for prototyping. It's not what I would design if I was trying to design the radar to do that job. I would design something else that I think is a do-able job and I also think ground clutter is part of it and will be a serious problem sometime. It is not a serious problem at other times, and I would think very, very carefully about antenna designs, radar designs, and if you are clever about your scanning techniques, you can minimize your ground clutter problem. I don't think ground clutter is necessarily going to be that bad all the time.

I think you get into two areas in analysis, one is ground clutter rejection and the other is pattern recognition in the presence of noise. The ground clutter is the noise and then you recognize the pattern exists there. I think we simply have to go out and touch the data. My experience with looking at a microburst from the airborne radar (and I'm probably the first one that's ever done that with the airborne Doppler radar) was that I could see it just fine. I was looking down more than we are talking about here, but I also had cases of where I was not looking quite so much straight down. I was looking down at 20 or 30 degrees rather than down 80 degrees. There was contamination there, but it wasn't rampant contamination that would have in any way prevented me from seeing that there was a microburst.

Crabill: Was that microburst a wet one or a dry one?

Hildebrand: It was wet. I also have some observations that are fairly dry coming out of Colorado: high-based, thin cloud with no gusts to produce any convergence coming down...The P3 radar we did our testing with is nowhere near as sensitive as this. It was a very useful radar and that's one reason it prompts me to say that we don't have to control the radar this well to see microbursts. It has cruddy beam patterns, considerably reduced sensitivity, and we can still see it.

Unidentified: I just don't think this is applicable to an approach problem where a sidelobe clutter problem is really severe. You are too close to the ground there and I just really think when we get into simulation and the like, I'm like Leo, I don't see the applicability of looking down 30 degrees to the approach problem. It just seems to me that it's ridiculous.

Unidentified: Well, definitely there's part that is certainly not applicable to direct simulation of ground clutter impact on the measurement. In that regard it's not applicable. In all other regards, I guess I...

Hildebrand: As a matter of fact, from the point of view of simply measuring phenomena, if you ignore the presence of ground clutter for the sample problem or the display problem, then it's a very simple problem. It's only in the area of ground clutter where Leo is entirely right: it is a different problem.

Bowles: From your perspective in having been around the JAWS Program, what kind of output product needs to be derived from the project?

Hildebrand: The product I would deliver to the air transport captain who is trying to take off and land is a product that is a combination of turbulence display and velocity derivative display that tells him about his turbulence intensity he's going to encounter at short range ahead of the aircraft or the velocity he's going to encounter at short range ahead of the aircraft, or the velocity gain or loss in the air that he's going to fly through. I would give it to him in concrete terms, both telling him the dangerous, and then the areas that would just be difficult to fly through. I would not try to tell him the exact velocity; I would just try to give him the warning areas, where red is in an area you don't fly, and orange is right next to red.

Bowles: You mean the kind of information that might be conceptually easy to integrate with other kinds of area maps and some display capability on board airplanes?

Hildebrand: Yes, I would try to present the data to the pilot in such a way as he could see concentric contours, such that the center was the worst area and there were lesser contours outside of that area. The reflectivity data display is an intuitively nice display. But a big velocity here and a little velocity here, with vectors going in different directions is a bit confusing. A number on a scope that says 14 is kind of confusing too, it's much better to have a picture. You can have the pilot see ahead of him some distance where he will encounter a place where he's going to lose a lot of velocity.

Robertson: My name is Roy Robertson and I think I've had the pleasure of meeting most of the folks in the room here, and I'm currently the manager of the Weather Radar Engineering Group at Collins. Being from an avionics manufacturer, I can say that without a doubt Collins is very committed to improving air safety for our customers and for the traveling public in general. So with that, I thank Herb and the FAA group for inviting us to be part of this. I think this is a great opportunity for everyone here to make advances and steps in this direction. We are a supplier as we have designed and are now producing what I'll call first generation Doppler radar for airborne weather detection use. Herb has asked me to describe some of the experiences we've had introducing this radar into the airline service and the kind of pitfalls that might be encountered. So first of all, we'll describe the radar and how it works and what some of the principles are, and apply this to both the airborne and ground-based scenarios. So, I'll talk about these and where we should be going in the future. There are some new advanced viewgraph holders here that are a little bit harder to use than some of the old ones. To give you an idea of where we've come in the radar business, Collins first marketed the WP101 and 103 radars in the early 1950's. These were among some of the first generation air transport equipment to go into service. Later on came the WXR80 in the late 60's and early 70's and it was followed by our product line of general aviation equipment. By the mid-1970's, magnetron-based technology had somewhat leveled off. New capabilities that were being introduced at that time primarily cen- tered around the displays, and the color tubes and the flat plate antennas. So, in late 1975, Collins began design studies to determine the concept for new advanced air transport weather radar. The objective of this new radar design was to do, first of all, a better job of precipitation detection than could be done with the analog set. Also, it captured some of the new digital technology that could eliminate a lot of variations and effects that were present, and could also do a better job of digital signal processing. Probably the most important would be to extend the capability beyond the conventional status; that includes the Doppler processing. In 1980, the WXR700 was introduced. This radar represented a number of advances over the previous analog equipment and included as probably the most important step, moving to a solid state transmitter. This is quite a drastic change. The solid state transmitter has roughly 100 watts of transmitter output for X-band and 200 for C-band. This is quite a drastic step compared to the radar we were replacing at 50 to 60,000 watt transmitter output power. This new radar was designed, and does in fact provide virtually equivalent performance to the older set. This was the first radar that embodied a totally coherent processing scheme, which means that the transmit screen and the receiving screen were hooked to a single crystal oscillator. It does preserve the phase angle of the weather echos all the way through. Digital signal processing techniques were used to the maximum extent possible. It, of course, incorporated color display and flat plate antennas that had been introduced with other systems at that time period. In addition, new capabilities were added which included Doppler turbulence detection and ground clutter suppression. The primary purpose of Doppler turbulence detection was to detect and identify thunderstorm-related turbulence. It primarily tended to an en route avoidance tool to give crew members a better view of what type of turbulence and other hazards would be encountered en route. This was based on much of the work done by NSSL (National Severe Storms Laboratory in Norman, Oklahoma), in the early 70's related to thunderstorm and encountered turbulence with radar measurement. Doppler turbulence detection does the measurement by actually calculating the velocity variance of the return echo along the beam axis. Like I said earlier, this is based on a lot of the work that was done by Gene Lee and others at NSSL. The related measured velocity variance as seen by the radar set did actually encounter aircraft turbulence. Their findings showed that a 6-meter-per-second velocity variance could roughly be equivalent to half a G turbulence aircraft acceleration and was the boundary of moderate turbulence. You start to see food trays being tipped over, and things like this. Twelve meters per second relates to about one G of aircraft acceleration, and this is the point where there is a possibility of structural damage. Turbulence detection is performed by doing a spectral width estimate at each discrete range along the radar beam. This is done using a pulse-pair process that keeps a continuous running estimate as the antenna beam scans through the storm volume. And due to the high interrogation rate required to keep the pulse-pair process running and the spectral width estimate running, this has a 50 mile range limit, which is more than adequate for the type of thing we're looking at. But for long-range planning purposes, it would be nice to have it a little bit longer. The turbulence display is then compared against the 5-meter-per-second threshold, which is some guardband against the 6-meter-per-second boundary. It is then displayed and overlaid on top of the traditional precipitation display. The pilot has a complete view of both the rainfall intensity and the turbulence that is being encountered in that and can make decisions accordingly. To give you an idea what sort of typical velocity variance might be encountered for the various targets, over here on the left-hand side ground returns exhibit the velocity variance generally below 3/4 of a meter per second. Weather returns, on the other hand, because they are distributive targets rather than point sources, exhibit velocity variance with a lower bound of 3/4 of a meter per second extending on up with 5-meter-per-second or greater being defined as turbulent weather. Another way to view this is taking a large number of velocity samples in a particular storm volume, with these samples representing a wide spectrum width that is considered to be turbulent because the narrow spectrum width is considered to be nonturbulent, such as a quiet rain storm would not be showing much velocity variance. What is the operational significance of the turbulence detection? Rainfall rate by itself is generally not a hazard to aviation unless it is very intense, at which point it can begin to affect the aircraft. Currently weather cell avoidance by flight crews is based on a number of indirect rules and measures that have been put together over long years of experience in actual flight. These include cell intensity, cell shape and gradient, other kinds of indirect cues that may alert the crew members to some form of hazard in that storm cell. Given these cues, there still are many cases that can escape the crew's attention, such as ice crystals at higher altitudes where the reflectivity is very low, low altitude and low rainfall rates where there may not be any distinguishing features, and in the early stages of thunderstorm development where there may be a great deal of convective activity, but yet the droplet size is too small to produce a strong radar echo.

This viewgraph is a weather radar display and the WX mode indicates it is working in the weather only mode, which means it is only measuring precipitation rate. This is showing a 20-mile selected range with the nose of the aircraft located at the apex of the display. The other range circle represents 20 miles from the aircraft. Off to the left is a well-developed thunderstorm and is showing light, moderate, and heavy precipitation. As you can see, there are other imbedded cores in this area. This would be avoided by virtually all airline pilots. On the right-hand side is a broad distributed area of low-level precipitation. This is not showing any characteristic signals would trigger danger in the pilot's mind. This next viewgraph is the same storm system, but with turbulence detection engaged. As you can see, where you would traditionally expect to see turbulence, there is none, and over here in the light rain, you can see a great deal of turbulence being displayed. If there were an airport located in that vicinity without this information, any crew member would not hesitate to just go on and land. But, he would wonder when he got in why he dumped all the food trays and shook up the passengers.

Unidentified: You mean this is actual data?

Robertson: This is actual data.

(Two simultaneous questions)

Robertson: The display colors are prioritized. If, for example, there was turbulence located in this area, it would be written over the highest intensity rainfall. So, the turbulence takes priority over any other level. We have found this to be the case in many instances; this is not an isolated case where we find turbulence disassociated from heavy rain. I can give one example: I was personally on an engineering flight test in 1982 and there was a weather system that covered roughly two states of just freezing drizzle over in Nebraska and Iowa. We were flying along in a Gulfstream and painting ground returns because there really wasn't much else to look at, just drizzle embedded in ground returns. We saw a very large area of turbulence following the ground return circle in front of the aircraft. We were at 25,000 feet. This went on for quite a while, and we thought, with this being an engineering test, it might be some kind of weird interaction between the ground and the light rain that was causing the false turbulence alarm. So, to get a better look at it, we brought the aircraft back around, descended to 11,000 feet and came out again, and sure enough, the turbulence was there on the display. In process of maneuvering and communicating with our traffic, we discovered that Omaha's Eppley Airfield, which was in our flight path, had been experiencing high surface winds, low-level wind shear, and they had just closed the airport. So, we had been seeing this for about twenty minutes.

Unidentified: Is this a picture at cruise altitude?

Robertson: This was taken from the ground. This number down in the corner is antenna tilt showing a degree and a quarter up. There have been other instances; these are very difficult to capture because normally when you're riding, you don't have data recordings along, but I was riding on a similar approach into San Francisco, when it was a rainy, cold, drizzly day, and we saw turbulence buried in the ground clutter and there was a very rough ride the last 1500 feet; we had a 36-knot surface wind. The pilot was doing a great job to get it on the ground. We'll come back to this in a little bit.

The next capability that comes along with Doppler turbulence detection is that of ground clutter detection. Because of the low scintillation frequencies of ground clutter as compared to weather targets, we utilized an amplitude process, which makes use of amplitude variances, as opposed to phase variances. There is a strong correlation between the two, and for ground clutter, it works much better. So, the threshold is now compared against three-quarters of a meter per second, and removed from the display. This only affects the precipitation display, as unfortunately as much as we would like, it does not uncontaminate the Doppler turbulence signal.

With our airborne Doppler radar, we had so much fun in the lab finding out where all the tornadoes were and everything like that, that we decided that there may be a market for a ground-based version of this kind of project. So, we did design a new display for it and a new antenna, took our airborne system and put it on the ground. This is a view of the storm system that came through Cedar Rapids in the spring of last year, 1984. This is where the radar site is located at our lab in Cedar Rapids, Iowa. This is the ground clutter pattern surrounding the site. This is a storm that came through, as we can see a storm front going through about to cover Cedar Rapids. I was giving this presentation to a ham club in town and one of the guys came up afterwards and wanted copies of the slides. He said that this storm at the time we had indicated had blown his brother's trailer over. He lived in a trailer court that was located under this pink-magenta area. So, I think that this storm represented a hazard to aviation if it was tipping over semi-trailers and mobile homes. This again gives a little different color scheme. This is light, moderate and heavy precipitation, with the magenta showing the detected turbulence of greater than 5 m/s. So, as the antenna is sweeping around, the range cells that are showing this weather are displaying a spectrum width of below 5 meters per second and those range bins that are encountered in the turbulence area are showing a velocity variance greater than 5 meters per second. The ground targets, even though they are very strong and showing level 3 returns, we would expect them to still have a low-level velocity variance.

Unidentified: For us non-radar guys, when you say a velocity variance, are you talking about between cells?

Robertson: No, the velocity variance is computed independently at each range location, each range volume; there is no connection. It's a comparison, if there is a range gate located here, it's a comparison of the velocities in that range gate itself, over a large number of interrogations, so the dwell time is sufficient if there is an independent estimate done at each individual range. It's a spectrum within that discrete range.

Pagels: Now, when you say variance, do you mean standard deviation?

Robertson: Yes, it's 1 sigma.

Hildebrand: Yes, but once contaminated with ground clutter, and your ground clutter has a small variance, isn't that superimposed, so how do you determine your variance there? It would be very small because of the strong signal returned.

Robertson: That is exactly the problem. We do not have an answer, and that's what Leo's research is intended to get after. If you have a weak weather signal that is riding on top of a very strong ground clutter signal, it will reduce the variance, exactly like you're saying.

Hildebrand: One of the ways that I believe the radars out at NCAR work, I don't know that you can measure the velocity right in close. How close in can you measure velocity in light targets, or do you have to be outside the clutter?

Robertson: It doesn't have as much of a function on a light target as travel time for your TR switch.

Hildebrand: You mean there's no clutter rejection on the radar?

Robertson: If you have a high clutter, clutter is higher in amplitude than the weather target, you are unable to really get a good estimate of it, is that true?

Hildebrand: Yes, we get back into Leo's problem that ground clutter is a serious problem, and I had to throw out a lot of ground-based radar data when I sent in the analysis.

Robertson: OK, that's one of the problems we are facing. I'll show you this picture here, the next photograph. When we were developing ground clutter suppression, it was in an airborne platform; we did virtually all our development work in a laboratory setting and in aircraft. It was a real battle to get ground clutter suppression to work on a moving platform, and we finally got it to work where we thought it worked very well in the air and we were amazed when we tried it out on the ground. One of these displays is with ground clutter suppressed, the other is for no suppression. This is with ground clutter in the display, one or two steps later, the ground clutter suppression was activated. There is an on/off button on the radar set that allows you to activate it, then remove the ground clutter and watch the weather.

Unidentified: What happens when the weather gets right near the radar?

Robertson: It makes a decision based on the strongest target. If this weather system was lying right over the top of Cedar Rapids, if the weather were the stronger target, it would be identified as weather and left in. If the ground were the stronger target, it would be identified. What it turns out is that ground is made up of a series of strong point reflections, towers, buildings, things like that, and those will show up as holes in the rainfall, so if they are stronger than the weather echo, it will recognize the characteristics of the dominant target at any given spot. This is ground-based radar, but this function also works airborne. This is the same implementation that we did in the air, and we got it to work pretty well in the air, and it worked much better on the ground. The ground-based problem is far simpler to solve than the airborne problem, and that's one of the points I'm making.

Staton: It might be of interest to note that the ground clutter extends 4 or 5 miles.

Robertson: Yes, so, this is really the kind of environment you'll see from an airplane to try to detect microbursts in this range. It's a tough one. If you take this radar and raise it on a platform a thousand feet above the ground, this ground clutter circle just mushrooms. Antenna pattern is everything, but still trying to find very light reflectors that are riding on top of a 40 or 50 dBZ ground target is going to be tough.

This next viewgraph shows another storm system. Again, you get to recognize this ground clutter pattern after a while. This is another storm that passed through Cedar Rapids, and it's showing a great deal of turbulence located over primarily an area near the small town of Alburnett, Iowa. And I have another picture of the same weather. The threshold was set at 9 meters per second. On the ground-based system we can adjust the sensitivity, adjust the threshold so it displays only the most severe turbulence. This is set at 9 meters per second, and at left the photograph was 5, so you can see by adjusting the threshold you can gauge the severity of the turbulence that is in the storm. In this particular storm, there is a fellow manager of our data link that works in the next office to mine, who was standing on his back porch and at the time this photograph was taken, the sky was just totally black. The wind came up out of nowhere, blew down a barn, a garage, and killed two of his horses. So, I have another recorded event that I can guarantee to be a hazard to aviation that is being picked up by this radar. So, this is the kind of data that is available in the present day system, that's not available with most of the radars that are flying.

Unidentified: Is the turbulence adjustment a viable option on an airborne WXR-700?

Robertson: Well, it could be done, but I don't really think it's desirable to do. As you can see, the decision is that one of the properties of a variance display is that it is either there or it's not, and if it's there you should stay away from it. It's a very simple decision to make. You design into that equipment where you want that threshold to be set. We use the same antenna for both ground and airborne, a 30-inch flat plate antenna. Nothing prevents us from using a larger antenna, but we decided to work with the 30-inch antenna. The range is 50 miles in the turbulence mode. This is a 200-watt radar at peak power. This pulse length uses, in this case, about 6 microseconds, about a mile, a little over a kilometer.

Crabill: Did you do some comparison tests using the S-band Dopplers?

Robertson: Yes, we did. The results were a rather subjective determination that what we were showing was reasonable. In their variance display, there's quite an enormous difference between their S-band, particularly in pulse volume and beam width as compared to our pulse volume and beam width. In the areas where our system was operated, there were ground-based and airborne tests that were done, and they show that...where our system is showing turbulence, that there is also variance being displayed in the S-band Doppler.

Crabill: Was there ever a report from this?

Schlickenmaier: Yes, there was, Norm, and I can get you a copy of it.

Robertson: The antenna is mounted about 50 or 60 feet above the ground level here, and the antenna elevation in this case is about level.

Bowles: Do you agree that the first moment is mean wind and the second moment is turbulence and given that the atmosphere doesn't separate itself very clearly in terms of what's wind shear, a change in the first moment, and what is turbulence? Could we be talking about similar things here?

Robertson: Absolutely. It's an important question, and it's a point that people get hung up on, but it's got to do with the scale of turbulence: a big scale turbulent eddy might be seen as a velocity shear from day to day, a small one might be from minute to minute.

Bowles: Right; we know that we have not really put good definitions on what is wind shear and turbulence, from an operational, aviation point of view.

Robertson: And Doppler people will give you another set of definitions, because their lines have to do with pulse lines, which to someone flying airplanes doesn't make a whole lot of difference. And that's why I think the integrated display that you want to end up with has got both gate-to-gate shear and turbulence effects going together.

Unidentified: Couldn't we argue that if you had a resolution of say, 100 m, you wouldn't be able to measure turbulence?

Robertson: No, not all.

Unidentified: That's why he's got to have a wide, coarse resolution in order to measure turbulence.

Staton: No, the turbulence is in the 100-m cell. Yes, but much less than what's in a kilometer.

Robertson: If he knows the scale of the pulse line, he can calibrate for that, because he has a turbulent cascade of energy and can scale properly and still measure it.

Unidentified: Well, you know there's a limit, depending on how stable your local oscillator is. You know, if you get the resolution small enough, you won't be able to tell of any turbulence anyway. The bigger your resolution cell, that is, the lower your resolution, the easier it is because the variation is so much larger in a kilometer than in a tenth of a kilometer.

Unidentified: Yes, but on a scale of some tens of meters, the turbulent velocities can change by some 50 or 60 meters per second.

Unidentified: You mean the velocity changes by 60 m/s in a hundred meters?

Unidentified: Yes, an airplane, at that scale, has measured turbulent velocities of that magnitude. There is a power law for the distribution of this stuff. We can multiply and bring it up. It's there at all scales.

Unidentified: Yes, but the problem is that you have to have a very highly stable frequency reference in order to measure a very small Doppler shift. And that makes the thing more expensive. So, if you want to measure turbulence, maybe the resolution isn't quite as important.

Robertson: That gets back to the question of whether we're trying to learn about the physics of the storm system, or whether or not there's a hazard there. There's a big difference.

Robertson: This is a vertical slice of another storm and I just put this up to illustrate how we've seen turbulence and patterns where it might fall. The antenna is fixed and is slicing down in this direction at a fixed azimuth angle and we are scanning vertically and producing this turbulence. And, as you can see in this case, the turbulence is accompanying the heaviest rain shaft in the storm. This falls into line with the definition of the mechanisms that create turbulence in some of the NSSL work, where you have boundary layers between the different rainfalls and downdrafts. We have, on the other hand, seen layers where an RH (range-height) scan will show a relatively constant flat layer of turbulence that extends horizontally, not at the surface level, but it may be a few thousand feet above the ground, maybe tens of miles long. We've also seen areas where the turbulence may be appearing by itself--for example, there might be a small patch of turbulence that shows some horizontal or vertical extent, but it's just isolated out there by itself. This can detect turbulence somewhat below the green display level. The green is calibrated at 20 dBZ, so in close it's more sensitive than the precip level. So, what's happened with these isolated areas of turbulence is that within a few minutes, say less than 5, it's developed into a thunderstorm. We have seen this actually from an aircraft, where we see a small area of turbulence, maybe 10 miles in front of the aircraft. As we approached it, we began to see green around it; by the time the aircraft went around it, it was a well-developed thunderstorm.

So, one of the root questions when trying to address the wind shear situation is: How far can existing turbulence detection be applied? Originally, it was designed to do one job, thunderstorm avoidance, but our experience since this time has shown us that we believe it can be applied to many more situations. It is not an end-all solution, it does not detect dry microbursts in Denver, it still has to have significant reflectivity. But, we believe that there are a significant number of these events, of all types, that do contain enough reflectivity and do show enough variance as measured by radar to trigger a warning display.

Unidentified: Could you put a number on that reflectivity level?

Robertson: At a couple of miles, it might be down in the maybe 10 dBZ range; that's plus 10. It may be true that the weakest case is minus 10, but they are not all minus 10; some of the accidents have been embedded in rain so heavy that you had to shovel it out of the way.

Where are the limits and where are the percentages of events that would be picked up? We believe there are some, but we don't know what that is.

Bowles: I would encourage the radar community to try to put a definition to what they consider...rather than to leave it to the discretion of...

Staton: Minus 10 is pretty dry.

Robertson: I've heard reports that even what's considered to be clear air, but may contain insects or suspended droplets that weren't fully evaporated, is showing reflectivity in the 5-to-10-dBZ range in the outflow range, and people don't know necessarily why, but they're showing these reflectivities.

Staton: It doesn't really mean anything, but if you take the standard formula that relates rainfall rate to Z, it means nothing down in this region. If it rains at minus 10 dBZ for Noah's 40 days and 40 nights, then you accumulate only three-tenths of an inch of rain.

Robertson: I have a little bit more to go so I don't want to dwell on this, but this is a very key question in our minds from a practical point of view. The first step towards solving wind shear problems is to make the best use of what's available, and knowing what performance capability we have in place right now is very important to build further wind shear detection schemes. We have roughly 400 of these turbulence equipped radars in service right now, and getting the most out of these, I think, is paramount as a first step.

Just so I can be honest, to what Herb asked me to do instead of come here and give you a sales pitch, I'd like to go back and review where we've been with this radar. It's pushed the state of the art in a number of areas and anytime you introduce new technology into a marketplace as dynamic as the airline environment, there are bound to be some problems, so I'd just like to bring you up to date on the kind of issues and things that we run into.

When we introduced the system, as you might expect, the crews had been flying the black and white set for 25 years and it's pretty darn hard to take away something that they have grown to know and love over the years. So, the first thing that happens is that we start getting a lot of complaints, and oddly enough the complaints were not with turbulence detection, we didn't have it right at the beginning, but this carried through to when we did have turbulence detection. The problems were not with turbulence detection, they were with the basic radar functions. So, a complicating factor was that alien radar interference, that's where two radars shine into each other's antennas, and that produces an unfortunate but target-like characteristic, and it makes the radar sometimes show what they call false targets and they therefore lose confidence in the system. So, as a result of the problems with the basic radar precip detection, the benefits of turbulence detection were not realized in the beginning.

Unless they can trust the set in traditional terms, they are not willing to use it in anything beyond those...they are not willing to understand turbulence or learn how to use it.

Unidentified: Are there disadvantages to the newer sets?

Robertson: These new radars are a lot more stable, frequency-wise, than the older sets. There is a lot of immunity gained just by the fact that the old ones were all at a little bit different frequency, working on different PRFs. These new ones are all, unfortunately, right on the same frequency, both RF-wise and PRF-wise, and they get to be synchronous at times.

Unidentified: I wonder if I could add: There was a problem we seemed to run across with the manufacturers. It was not particularly germane to Collins, but I understand Sperry and Bendix ran into the same sorts of problems, the same sorts of questions came up. They eventually put together some sort of resolution of the basic reflectivity on the color weather radar. You could talk to Neal, who always loved his black and white monochromatic weather radar, because it always worked and he always understood how it worked. Most of the pilots who were used to those, there was a fair amount of confidence of the digital technology that was produced across the board, there was...

Robertson: Here's something that needs to be addressed as an item: we increased the loop gain, which means we made the radar more sensitive. We eliminated alien radar interference, and lastly, we've improved the display processing for a better picture, to make it easier to identify weather from ground. So, our present situation with the airlines is that we have 800 of these aircraft equipped with Collins radar systems, 400 of which have turbulence detection, and now their basic performance is meeting the needs of the crews. They're happy with it. Many of them are telling us that they prefer it over the older sets. And, as a result, we are now beginning to very quickly learn about how to use Doppler turbulence detection. I rode with a United crew the other day, and the captain was explaining that on the same day as the Delta crash, he was making an approach into Cheyenne, Wyoming, and he noticed these high-based virga coming at him, and he really didn't think anything of it. One of them was in his flight path, and he was going to go through it, but his copilot wouldn't let him. And, as they came into range of the Doppler mode, they saw the core of this virga about 10,000 feet above the ground just swelling with turbulence. Just beyond the range of the radar there was another virga that had just hit the ground and was splashing and blowing dust out, and so here is a case of detecting turbulence in the core of a virga in the same area where there is a visually sighted microburst.

Another crew described flying along a line of thunderstorms and seeing turbulence that was outside the green area, which is entirely possible. And, he was just getting pounded, and by searching his altitude up and down, he finally descended to 11,000 feet, and found his altitude where there was no turbulence being displayed on the radar and his ride smoothed out. And, I can just go on and on about reports that are unsolicited, of crews that are learning to use this. I think that it is going to be a powerful tool.

So, what have we learned from introducing a new technology radar into the airline marketplace? One of the most valuable lessons I think is that the equipment must be proven in a user's environment. What may work perfectly well in a 25,000-foot, 250-knot airplane, may not work at 40,000 feet at 500 knots. There is a big difference. So, it must be proven in a user's environment. Secondly, as a manufacturer, we have a very poor communication path with crew members. In many cases, the airlines themselves have poor communication with the crews. Our customer is airline engineers and operation people, and so we're one step further removed. As a result of that, feedback as to how the system is performing is delayed. A lot of time there is not even a path between the airline and ourselves, because they are trying to work their own problem. So, before we find something out, it may have been continuing on for a year, and may have been aggravated into a big problem instead of a little problem.

Another area we found particularly difficult from a manufacturer's point of view is crew education. We, as a company, cannot train each individual crew member at all airlines. That has to happen through the airlines, through their training programs. We can provide information, but we can't disseminate it. We've issued pilot's guides on how to use the system, and we found that getting the crews to read the things is very difficult.

(Unintelligible question)

Radar is very weather and season-sensitive, and in December there is absolutely nothing happening, so all the radars are turned off. There is no rain in this country. But come about March and April, it just goes through big cycles, whereas in the middle of summer or after, radars are picking up airplanes and the activity is really peaking. So, what I'm saying by this last statement is that, because we are not in touch with the crews directly, the information has to be the aggregate of a large number of individual reports of crews, and finally, the message comes across to us. And, before we get these messages or feedback as to how the radar is working, a large time has elapsed. In many cases, it may be an entire summer before we ever find out what's going on. The point I'm making is that there is a long time delay. We've found that one of the most effective ways to circumvent this is to get in the jumpseat and go fly with the pilots. We spent a better part of the last 12 months in the jumpseats learning we can do one-on-one training, we can get one-on-one feedback and see the operation of the equipment in a pilot's environment, and see how he uses it, and whether or not it is serving his needs, and right there when he is having problems, and find what's going on and see it. Because the reports, by the time they ever get to us, are so diluted and paraphrased along the way, that we spend a lot of time looking at tabular data and finding nothing. So, until you get in the cockpit, you really don't learn very much.

Looking forward, there is a major challenge ahead in the industry, and how do we solve the microbursts or the wind shear problem. And, I've found that this next part of my presentation has already been given in one form or another by virtually everybody on the floor here. The development of any new devices is going to have to rely on simulation;

there is just no other way. In order to develop accurate radar models of the wind shear, which will allow looking at the wind shear event from an approach angle in the ground clutter pattern, we must have those simulations. To get something new to try out, it's just not possible to get in an airplane and go and try it.

Another point that was made by Cliff Hay this morning was that the problem must be defined so the solutions can come incrementally. It's our belief that today there is a partial solution and we need to learn how to use it in the turbulence detection. But, if we wait until we have the total problem solved, it may be 15 years from now. We need to define it so that with this level of improvement in technology, we can gain this much more of a percentage of a solution by increasing technology, another step to gain another level of improvement. I don't believe it will come all at once. Right now, the information is not available for us to quantify the effectiveness of any given level of technology. The training should be treated up front as a key part of the solution. It has to be planned for and treated as much as any part of the development theory. That is, so to speak, where the rubber meets the road. Where you get the crews using it, they have to know what is going on. The last item here is that the solutions have to be commercially realized. If it's something the airlines can't afford or won't fit into the airplane, then it is not a solution.

Some of the issues looking ahead: I think there's been a lot of discussion on display. Radars have traditionally presented broad data to the crew and it's up to the pilot, based on his own flight rules and observations, to decide what to do. In the case of wind shear detection, the broad data is going to be very complex. So, whatever the wind shear detection system ends up being must reduce it down to a go/no-go type of decision. Turbulence detection is that kind of a solution, in that it's there or not. If it's there, you don't fly into it.

Unidentified: About your threshold, that's 5 m/s, rms, 1 sigma. You're saying that if the radar indicates above the threshold, you don't fly into it, you don't make the schedule. That's a pretty powerful statement to make, to tell the pilot that.

Unidentified: If I were riding with the captain on his approach, and I saw the turbulence in our flight path, I would suggest to him that he go around.

Robertson: I don't think that that is a particularly debatable topic. The airlines make decisions where they are going to put thresholds. They decide where you're going to color the reflectivity red, where you're going to color it green, whether you're going to color it green or blue or any color they want. And, this is just another decision, some group of people is going to make it.

Unidentified: My point was that it's an example of a go/no-go type of a presentation, where it's not an interpretable quantity; it's either there or it's not.

Unidentified: We could write that into the procedure manuals.

Robertson: All right, the second bullet here, the verification, is extremely difficult. How do you know when it works, and how do you prove that it works? In thinking about this question, I contacted our flight control people and asked them how they certified the first automatic landing system in this country, on the L-1011, and the answer I got was quite surprising. They virtually certified the automatic landing system based on simulation. They ran roughly ten million simulated automatic landings, over which they exercised the performance to all the different limits and parameters they could think of, for both aircraft dynamics and environmental conditions. In the actual flight test program with FAA observers on board for the certification of the instrumented automatic landing system, there were only about 100 automatic landings conducted. And the major purpose of those landings was primarily to validate the simulation model. So, this kind of a problem just about says that simulation is the only way we're going to get there, because it just isn't possible to go fly a hundred microbursts in any length of time. So, how do you define the probability of detection and false alarm rate from these rare events, particularly when they are in such a broad spectrum of circumstances in which they can occur?

Lastly is the certification and liability question. Right now turbulence detection is certified on a no-hazard-to-flight safety basis. Which simply means that we are allowed to put turbulence detection into the airplane on the condition that it not interfere with any of the traditional functions of the aircraft. Now, if someone were to make a claim, I think that this might get at your question. You have had no applications for certification of a wind shear detector. Isn't that true?

Schlickenmaier: Yes, it is.

Robertson: If someone were to claim that they had a wind shear detector, how in the world would you ever prove that it worked?

(Unintelligible question)

Schlickenmaier: They're running under the same liability. They have supplemental-type certificates that there is basically no hazard. It means that you can't interfere with the other instrumentation aboard the aircraft. And, if you see their ads in Aviation Week, it does say...certificated safe flight wind shear warning system.

Unidentified: Kind of like a nonstandard ashtray.

Schlickenmaier: That's right. Procedures are roughly the same.

Unidentified: That's absolutely right.

Schlickenmaier: OK, but the procedures are in place to do the full mission.

Unidentified: What do the letters STC mean?

Schlickenmaier: Supplementary Type Certificate.

Unidentified: Right.

Unidentified: Or how about Sensitivity Time Control, for us radar guys?

Unidentified: Hey, yeah, that's right!

Bowles: The major airplane manufacturer in this country may be coming through with a system.

Schlickenmaier: Matter of fact, there may be somebody else.

Bowles: (Inaudible)

Schlickenmaier: I understand there's somebody else. There's another organization that is looking at the certification issues. The prime organization right now is Ray Sellers, in the Northwest Mountain Region (of the FAA), who is concerned with the issue of certificating wind shear detection/avoidance packages from the airworthiness end of it. That means the engineering work is...and as I mentioned earlier, the only other thing we have on the book is...which, as a matter of fact, does rely heavily. When I wrote the appendices to AC 120.41, it is almost exclusively simulation-based.

Robertson: That gets us right back to the models. We can't do radar simulation without radar models. We need data of a microburst, ground clutter, at -10 dBZ. With that, I'll conclude my speech.

Bowles: Within your organization, are you now attacking the problem as part of IRAD?

Robertson: As a manufacturer of Doppler radar, we are constantly aware of these issues, and although I can't state that we have a major wind shear development program in house, I can say that there's a great deal of interest and support for this project.

To summarize my presentation, let me say the following. As I explained at the beginning of the presentation, in the turbulence detection is a velocity spectrum width estimate, and it measures essentially how rapidly the velocity is fluctuating at each individual range cell. There is no connection between one range bin, so to speak, and the next range bin. They're each doing an independent spectrum width estimate. This threat, if the velocity exceeds 5 meters per second threshold, then it's detected as turbulence and overlaid on top of the weather picture. In conjunction, you have the normal precipitation display and the turbulence is displayed on top of it, so the pilot can see the relationship between them.

Unidentified: Is this an existing piece of hardware?

Robertson: Yes, this is our WXR700 air transport radar that we currently manufacture, and we have roughly 400 of these turbulence-equipped systems now in service. We have also adapted it to ground-based applications, taking essentially our airborne system and put a different display on it and a different antenna pedestal, put it on the ground. We have quite a few of these. The National Weather Service in Minneapolis...

This is an example of an airborne weather display showing weather mode, 20-mile selected range, and one and three-quarter degree tilt. This is the photograph taken from our lab, so it's on the ground. Now this is what we found to be quite a common situation, and not remote. This is a well-developed thunderstorm that is showing light, moderate, and heavy precipitation, and will trigger all the warning signals in any pilot's mind, to stay away from there. They know to stay away from odd-shaped storms and from areas of high reflectivity. Here on the right is the very broad area of just light generally scattered rain; it doesn't show any characteristic danger, so that would not trigger a warning in anyone's mind, and if there was an airport in this vicinity, there would not be any pilot that would hesitate to land there. This is the same weather cell, but with turbulence detection activated. As you can see, where you would expect to see turbulence in the heavy rain shaft, it's not there, it's over here in the light rain. In today's non-turbulence radars, there are no warning signals or cues, but if a crew would land there, they would get beat up on the approach. I've been on approaches where we have flown in turbulent areas, and it's rough, so with this, the turbulence detection is giving the pilot an additional piece of information to make his avoidance decision that he wouldn't have without it.

Unidentified: When you said with "it," do you mean that you sell a commercial Doppler radar?

Robertson: Yes, we do. Our first Doppler-equipped system went into service with United Airlines in February of 1983. We introduced the radar first of all as a new solid state unit in 1980 in a non-turbulence version, but then we upgraded those units in 1983. Now United Airlines is flying roughly 120 of these systems in their fleet, and worldwide, we have nearly 400 turbulence-equipped aircraft.

Unidentified: How does it work if there's no precipitation?

Robertson: We must have liquid water to detect turbulence, to detect the velocity variance. We have since adapted to ground base. There is one other company that manufactures these. Another example: I mentioned we have taken the airborne system and adapted it to ground base usage where we simply have taken the same radar set and applied it on the ground. We put our color display on the map so you can see where you are. Along with the Doppler processing comes a thing called ground clutter suppression. Now with a very stable transmitter and receiver, it's a coherent system. Transmitter and receiver are phase-locked together; they are both driven by the same crystal oscillator, so the phase angle of the weather echo is preserved. This is a storm system that passed through Iowa. This is from our laboratory with radar location in the center of the picture. These echos in this area are ground returns surrounding the site, and this is a thunderstorm system that is moving in with light, medium, and heavy precipitation in the orange. The detected turbulence is showing a variance of greater than a 5 meter per second, indicated by magenta, a pinkish color, which is overlaid on top of the weather in the area where it is exhibiting a higher velocity variance. In this particular case, there was a recorded damage of a mobile home court where there was a semi-trailer tipped over. So there was damage recorded at the site the day of this event. Well, this is indicating a hazard to aviation most definitely, since it was able to do damage to the ground. The point of this slide here is that this is the ground clutter, which normally exhibits a very low velocity variance, less than three-quarters of a meter per second. Storm turbulence has a velocity variance of greater than 5, so they're at opposite ends of the same spectrum. Now, with the ground clutter suppression circuit activated in the radar set, this is the same weather storm. This has ground clutter in the picture, but on the next sweep, the ground clutter suppression was activated, and as you can see, has been taken out of the display.

Unidentified: If there has been turbulence over the site of the radar, would that simply blank that out?

Robertson: Well, the ground clutter suppression only estimates the precipitation displayed. If there was turbulence detected, that would still remain in place. This ground clutter suppression technique does not uncontaminate the basic signal. If there is a higher amplitude ground clutter with low-level turbulence signals, like if you have downtown buildings, for example, with light rain over them, the building is going to dominate the return. Therefore, it would take out the building and any strong signals that dominate the return. But the ground clutter suppression we developed is an airborne identification tool where at 100, 150 or 200 miles, the pilot could use it to remove the ground clutter and preserve the storm echoes, so he could tell at long ranges whether it was ground or weather he was looking at in his display. We developed this method for airborne use and got it to where it was performing, we felt, very well. You can see storms at nighttime and thunderstorms at 120 miles when you push the button. You know it is embedded in ground returns. Push the button, and the ground returns go away and the cores of the storms stay in there. When we tried it on the ground, it was absolutely fantastic. It worked much better on the ground than in the air. Reason I'm making that point is that the airborne problem for both turbulence detection and ground clutter suppression is far more difficult to solve on a moving platform than on a fixed platform. This is an example. This is a piece of cake to do this. Whereas in the air, it is not; it is more difficult.

Unidentified: Still, you didn't resolve the problem of measuring anything in that area.

Robertson: No, we didn't. What we are trying to do, turbulence detection was originally put into service as an avoidance tool for thunderstorm-related turbulence. There was a lot of work done in the early 70's by NSSL that related thunderstorms' turbulence to variance echoes or variance measurements, made by Doppler radar. So, on that basis, variance was used as an indicator of thunderstorm-related turbulence. Since that time, now we are applying it to new areas, some of them being microbursts or other wind-shear-type hazards. We are exploring where it might be applied beyond what we are doing right now. That is kind of where we are as a manufacturer.

Schlickenmaier: Thanks, number one, Tom Campbell and his people for putting on an absolutely first class forum for us to discuss openly numerous issues. And to Ginny, thank you. Without you, we couldn't have pulled any of this off. We need to focus on tomorrow. I think we had good overview today. I'd like to scope out a couple of areas. One, the airborne Doppler wind shear detection and avoidance system: what are we scoping? Where is the area we work? I think we heard two numbers. We heard from Mark Kirchner of NRC, who says 800 feet down to the ground. We've heard some other numbers in the thousands, around two thousand feet to the ground. I think we also need to start defining what that is. I think we also need another question to ask. What is the intended flight path, and how do we work within that? Boundaries, five to ten miles around the airport? Closer, strictly along the flight path, or are we looking at spreading out the beam in the traditional weather radar mode, or will we be looking at something like the...Keep in the back of your mind what I think is a goal, and the goal that Roland expressed is part of the proposed NASA program. We would like to come up with some sort of hazard criteria to define the wind shear hazard to the flight crew in terms of a go/no-go decision. Whether that means the light plane...or it means the flight director gets into the wave-off or go-around mode with pitch/steering commands, suggesting a flight path escape route, I don't know. The concept of integrating the in situ present position data with the predicted data--how important is that? How can we effect that mix? How can we give confidence to whatever weather radar data we design for? And, the bottom line, as outlined in the plan, I hope...although some of the in situ flight guidance and control systems we may be looking at, we are looking for systems that few people have, means of escaping or avoiding wind shear, or maximizing crash survivability in hazardous meteorological areas. I would like to suggest that the trap that we once walked through was a trap of defining meteorology or of classifying wind shear. For a long time, frontal shears were the only thing that were listed. Then downbursts. Then microbursts. Now all of a sudden we are getting all of these other things in aerodynamics and rotational flow...I think we've seen from Peter the ability to do some rather remarkable meteorological sensing. I think of what we have seen from Collins and what we know from other manufacturers...

(Next day)

Campbell: Thank you very much. One thing I would like to mention is that...forgot where we left off. I believe that we were in the area of discussion and I would like to comment that anyone who would like copies of Roland's or Leo's presentation, we do have copies of them. You can pick them up on your way out, and thank you. Herb, how do you want to lead off today?

Schlickenmaier: Well, I guess we are all reasonably well versed as to what's going on. What I would like to open it to, if we could, is to see if we can put something in perspective, from my point of view. Do you think we are at a point where we can put a series of tasks together and assign some sort of relationship as to how those tasks might be instituted? I wouldn't necessarily set people up for commitments of time. There are several relationships for how we might be able to come up with a wind shear detection and avoidance package or methodology. Along the way, we can identify what some of these products are. You know I tried to tickle some imaginations last night before we left. In terms of things I think we need to be addressing on the technical side, can I open it up for more discussion? Peter, Roy, Roland, Jack, guys? Comments, thoughts, questions?

Hay: Well, one thing I got out of this is that we're really discussing two different kinds of wind shear radar. One is for diagnosing and defining what wind shear is, so what you need there is a fine-detail radar if you are talking about a pulse Doppler. Here you want narrow pulses, higher power so you can get intimate information on what the wind shear is. And, from Roy's discussion, I get the idea that you don't need the detail just to discover that there is a wind shear problem out there. You could use a far less resolution radar, and much easier to design by the way, and detect the fact that there is probably wind shear out there, but you really can't define it in great detail. I think those are the two areas that we're sort of talking about. Really, two kinds of radars, one for discovery and analysis, and the other one, practical purposes and for installing on airliners.

Hildebrand: Well, I think to pick up on that, if you really want to attack wind shear in the last little bit right in front of the airplane, where you are going to get to in the next minute or so, you want to design your radar considerably differently from how you design a surveillance radar. That doesn't mean that the same radar can't do the same job, but you should use the available capability of a radar system that can generate an average transmit power in a different way. If you can do that, then you open up some new doors in sensitivity capability. And it seems that there are some possibilities to design such a radar that will work in some certain span of situations. Won't do the whole job, but it will do a reasonable part of it.

Robertson: I basically agree with that. We really do have two types of radar, and radars can be designed to detect these things. But a better understanding of the meteorological conditions in the environment that they occur in, then the kind of critical design tradeoffs can be made that specifically go after a certain subset of cases. But, I think that the key to that is understanding what the environment of the microburst is and defining what the events are, so then radar design could be optimized to go after those characteristics in that environment. So think of feeding that thought process to the expansion on the modeling capability. Modeling computer simulation of microbursts in radars--radar in software, so to speak, that can then be used to test out some of these various scenarios.

Fedors: I guess I would like to see the problem defined a little more in terms of the lots of numbers I heard yesterday about, where you began to detect this, and what Roland mentioned, four minutes plus, or minus four minutes as a matter of fact. I would like to see a scenario for radar to attack. Four minutes seems an awful long way out. It seems a long way out to be looking for these things based on what I understand from Leo on the lifetime of these microbursts.

Schlickenmaier: Roland, do you want to make a stand on this?

Bowles: Yes, what I said was we have a span of time over which you could be looking, from the outer marker on in. What I was suggesting is that a 40-second look-ahead would give us a feeling for what the data base would say if you had a three-sigma...

Unidentified: How much of a problem do you see in separating out the ground clutter?

Robertson: I find it a real significant problem just from flying approaches with the existing radar sets that we have; the ground clutter virtually smears the picture. With any kind of a level antenna pointing angle and ground clutter echo, replies can be either 30 or 40 dBZ equivalent reflectivity. Your weather phenomenon is down near zero dBZ, it is essentially a very high level signal blasting the receiver out and the little wiggles on that waveform represent the wind shear. So, I see it as significant problem, and I think there are a lot of areas of maybe scanning strategy with the antenna that could help that a lot, but the basic problem is that on an approach it is still a very shallow view, and without very sharp characteristics, then still in order to get down to the very low altitudes required to detect this, ground clutter is a part of nature. A typical approach angle might be 4 or 5 degrees up in tilt. On a typical approach the pilot would run his antenna maybe 5 degrees tilt up just so he could still clear the beam on the ground.

Unidentified: Without clearing the weather phenomenon that you're looking for?

Robertson: In this case it is. Now he, if he is avoiding rain that is coming down, he could still see it, but, the point that I'm making is that to clear the ground clutter for any level the tilt angles required to see wind shear would be very low on the ground and this would be a very difficult situation.

Unidentified: Do you or Collins have an approach that you would recommend to tackle this?

Robertson: Well, I guess to say offhand we don't, because there has been a lot of literature published, and MIT has done a rather exhaustive study of the different techniques, but, again, these are basically applied to the ground-based or occasionally a platform case. I think when you get into the moving platform area, there is a lot different consideration there. I don't think there are lots of opportunities to solve these; you have to do a lot of the solutions numerically because we know what our microbursts look like. We can define what the domain is that we have to look at. We have a model for what the atmosphere looks like. So, we can define what is the signal we are trying to measure, and that gives you some specs on what you hope your radar measures after you solve these problems. You need to understand that, and you can also attack the problem at that point of what is the domain you really have to sample on, and that will give you some bounds on how you do the radar design. I'm not convinced that you should do it the way you design a surveillance radar. Maybe some new sampling techniques would help the radar problem. Because you do want to get sensitivity out of it. Well, the other problem is how do you handle the ground clutter problem, and it seems to me that there is an opportunity with our knowledge of what the meteorology is like to do a lot of that design work numerically. You can specify as high a resolution as you want to...the reflectivity structure, and, the ground clutter structure. Now you have to go out and make some measurements for your ground clutter structure to fit, and hopefully JAWS and then CLAWS and then MIST and all these other programs will help some more in numerically modeling the meteorology. So, you can have a model of meteorology and ground clutter with any resolution you want. You can then go sample that with a numerical radar. You can sample with realistic beam functions, sample the ground, sample the atmosphere. From that you can construct the Doppler spectra you should get, and the nulls, and the IQ output of radar, which then you could either process in a spectral format or a pulse-pair process or format, all numerically. Then that will enable you to see and then you could go back from those data and reconstruct what you get for velocity or variance. Go through the whole testing procedure. This is something that has been done. I've been peripherally involved in some of the research and I know it is possible to do this. It is not a job that requires a massive computer. This would enable you to figure out how practical the problem is--to try out different schemes of ground clutter rejection without going out into the field and hope mother nature gives you a microburst just when you happen to be awake.

Fedors: My question is, seems I never heard of microbursts before a week or so ago. Everything I have seen about these, every picture, every drawing, every representation I have seen shows these microbursts at a location where you measure them, and they are all drawn over a runway. Do these things move? Laterally, how fast do they move? I'm thinking about how to design this radar, and they move at surface velocity; they advect. When a pilot comes down this tunnel to the ground, when one moves across in front of me, with a slight crosswind...

Unidentified: That brings up the question: we know what a microburst signature is; as a microburst forms to the side of the approach path and advects across the flight path, do you see that characteristic signature at any time? Is it possible that the aircraft and the microburst actually come into confluence without the radar ever seeing the characteristic signatures?

Robertson: That gets the back seat. I think you need to separate the problem into practical sub-problems. You can't consider that question at the same time you are worrying about ground clutter. Basically, that says you should be looking out through some cone. And, the width of the cone is specified by a reasonable guess about advection velocities.

(Discussion involving several participants)

That's on the assumption on how far the beam is penetrating into the cell before you get the characteristic signature.

That is what I'm saying, you need to scan through some sections, but you don't need to scan out there because you are never going to get out there.

Maybe a steerable sector; the sector may just need to occupy trajectories like that.

Now the microburst can also just come at you from up above. You have to look up, because your sector is a cone.

Fedors: This gets worse.

Bowles: I think the point here is that if you go back to coming down from cruise altitude to near-on fix, down to 10,000, you've got an... and from 10 down, you've got...The ground clutter problem there is normal, right? You can search in horizontal slices all the way down. These things have telltale signatures; there has to be vertical flow somewhere, to have an outflow close to the ground, and the artists have taken a lot of liberties with the pictures of these things. The little boundary layer is literally 300 meters thick. It is not a mile. Now what I'm saying is that on the way down you scan; you look around just like you use weather radars today. You have terminal information systems working on your behalf, you've got terminal weather, right?

(Short discussion on NEXRAD, several participants, everyone talking at same time)

Unidentified: What you want to do from 2,000 down is short term. Now you are talking not about absolutes of nature, but what could nature do for me in relation to my early performance? Because now you are getting stabilized for approach in a low energy state, and this is where the hazard is, from 2,000 down.

Schlickenmaier: What we are saying here is that you don't turn this thing on all the time.

Unidentified: For instance, you may only turn it on if there is possible wind shear.

Unidentified: Don't turn it on until the reports say possible wind shear.

Fedors: The point, folks, is a small airplane doing touch and go's says he has turbulence in the area.

Hildebrand: We've decided that the optimum function is at 2,000 feet to touchdown, but from 12,000 to 10,000 the radar may have degraded performance because you didn't design it to work up there.

Unidentified: There are such things as multi-mode radars; the military might have ten different modes to accommodate every condition. Now, on this thing, I would say you could probably use it for two or three modes, if you are cruising at 40,000 feet and using it for normal radar stuff. Maybe something else at other altitudes. We don't know the answers to that.

Bowles: The advantage here is the fact that we do know a lot about meteorology in terms of spatial and temporal conditions. You could use that to your advantage. In other words, we at least know where the haystack is, we don't know where the needle is. We've got the right field which could be used to your advantage.

Unidentified: One of the assumptions here is the requirement for low grazing angle ground clutter, on which you superimpose your wind field for which you have a much better mathematical model. Then, try to put these data together, then subtract what you put into the mathematical model. Part of the experimental program would be a requirement to collect and work with realistic ground clutter in the sense that you would not hang up the models. Is there any disagreement with that?

Robertson: No, I think that is a very viable and important approach. I think it is necessary to undertake that kind of experimental program because first of all it tests the reasonableness of the overall ideas, and in a gross sense can even be extracted from the ground clutter. Secondly then, it also gives you a method or a tool in which to refine the ground clutter model with more accurate representation because any extraction techniques are going to have to rely in the large part on the very fine details of the ground clutter. That is not a gross problem, that is a...technique might leave out the details, so I think that the model of the ground needs to be refined over time. But, I think that it is possible and a very valuable thing to do to this. You have the answer, you know what the microburst looks like and you can model that very accurately. You know what the ground clutter model superimposed on that looks like, and you can get a process devised that will extract that back out. That is a very important step in this whole process.

Campbell: You know, I think there is a common denominator throughout all of these discussions, and that may be considered to be a subset, but that is antenna technology and sidelobe suppression techniques. That is not just a flat plate antenna that you attach to the radar and expect optimum performance. I'm thinking a lot of work needs to be done in basic antenna technology to make sure you come up with the right design for this application--and to alleviate some of this clutter problem.

Campbell: Well, I think from just talking we've cleared the area on what needs to be done right now, and kind of start from scratch.

Hildebrand: I think, as you mentioned, that it is pretty clear looking at a multi-mode radar operation, you know, where you have one mode just for surveillance and another that is your wind shear detection mode. Some of the work I have done suggests that in spite of the advantages of C-band for surveillance, you may want to go X-band for this kind of job, simply because of the beam width. But the pilots may hesitate to use it. That's another problem, but if you degrade that performance you are going to get into a different mode.

Unidentified: You need to mention frequency agility.

Hay: Well, that's one of ours, we are talking about Epsilon frequency agility. It's pretty hard to switch between C and X; you know when I say multi-mode radars, they are almost all very close to the very same frequency, but what they do is change their modulation characteristics, and I may make another comment about a low sidelobe antenna. Almost every case you want to get the narrowest beam you can, no matter what mode you go. You really don't have to change the beam width particularly. You can take care of that by scanning. Usually you always have too wide a beam width, and you'd really like to get it down. You can never get it narrow enough.

Hildebrand: But, it also turns out that if you make slight trade-offs in antenna illumination, you can get the beam a little bit wider and the sidelobes down, and you can pay a lot of money to do that. How much money can you afford to put in to do that in order to make this work? I think your point about maximizing the performance per dollar through something like putting the antenna and radome together can be very, very important. A system that does this well may require new specifications on how to build or treat your antenna and radar. You don't let your normal present aircraft mechanic touch that without special training. You don't need it.

Unidentified: This calls for original thinking. You just don't have an add-on feature; everybody is talking about the radar system, I understand this, it is very important, but I think we have to tear on a separate path...

Hildebrand: The radome is a very, very difficult problem itself, and maybe you design the radome to maximize its performance through some narrow sector and allow the beam, the pattern, to get worse in other places. That itself is a tough job, where you have probably a few artists in the country who can really handle it. Getting the job done is really important.

Staton: Antenna technology is certainly well enough developed to do the job; the question is can you do it in any reasonable cost? My answer is that it is not very good designing things to low cost.

Campbell: A lot of work has been done, but I think maybe a new twist needs to be applied to this product. There is a practical reality that it is pretty hard, it is kind of like a bucket of cold water in the face in dealing with the airlines' type of environment. I believe the system is going to have to be quite tolerant of imperfections. This may not be the technical job they were designed for. Our experience has shown that radomes get banged up and repaired poorly, and they sometimes get a little water in them. You know it's not a perfect system. That is another ideal. We ought to try to build something that can overcome all the ills. There are some real hard trade-offs that have to be made before it will work in the airline environment.

Unidentified: I keep hearing that these microburst characteristics are quite well known. Is there something written up so I can get a copy?

Hildebrand: Yes, I think there are the JAWS reports, in addition to the report that the National Research Council put out, and papers by Fujita describe microbursts to the extent that they are understood. And you know as long as you can allow the researchers to keep working on something, there will be more and more detail. But I think in a gross statement we do understand what microbursts look like. It is also true that we don't understand what a wet microburst looks like as well as a dry one. That's a design detail that will get cleared up as we work along.

Hildebrand: The forcing for a dry microburst is very easy to understand, because water drops evaporate. The forcing of wet downdrafts is different. I don't think it's quite as well understood. The difference between a heavy rain shower that doesn't produce microbursts and one that does is clearly understood.

Unidentified: Well, there are still some outstanding features that bear particularly on the radar problem, like the degree of shear that actually exists right down to the ground. The JAWS data doesn't show much. In fact, there is very little change between where the plots go to the ground, and the first few hundred meters. That is all important for the radar problem.

Unidentified: That is the gap we are trying to fill with the model. We are subtracting a small signal on top of clutter. The detailed features of that thing are all important. What you are pressing at is the gap between measurements on the ground in JAWS, assuming it is going to be there in MIST, and every other project and in the numerical model work that you and other people are doing. The point is it is still an evolving thing. We have to have something to give to Cliff and say, yes, this is the model, this is what you guys are really going to see.

Hildebrand: Well, I think we can, at this point, take the model and say this is an excellent third-order approximation of what we have. We can work with that and produce some results. This is the first time we have gone out and seen the phenomena. What he sees fits observation very, very well.

Unidentified: Is the JAWS program continuing, and will there be a follow-on to MIST?

Unidentified: Yes, the JAWS program was a one-year field program; it was followed by an operational attempt of CLAWS one or two years later, and the analysis of the JAWS data is continuing. There is some numerical analysis.

Campbell: Who is doing that? You?

Hildebrand: No, I'm not on the JAWS project. McCarthy and his staff are working on that, and there is some numerical work going on. There is still some analysis of JAWS data.

Campbell: This is all funded by NSSL?

Hildebrand: No, it is funded by the FAA. The FAA is the major sponsor of all this work. It is the major continuing sponsor of these types of activity, and a good portion of JAWS is also beamed at the training problem. But it is certainly going on, and there are plans for them to collaborate to some extent on the MIST program. But they are also moving more and more into operational. Let's try out protecting Stapleton Airport, as an exercise in terms of Doppler radar problems. So you can see they are going in another direction, and completing answering these problems, so I think it would be also proper to go back to JAWS and say, these are specific questions we would like some answer to to help this project. That kind of direction would be very well received by them.

Campbell: It would really be good to have a better understanding of the ground-based program. I don't have that much understanding as far as the new program and how its synergism could be obtained.

Hildebrand: If we could provide a list of questions about microbursts for JAWS, I think it would be a good list of questions.

Campbell: How many test sites are there; how many antennas are involved on the ground-based system on the long-range MIST program, I don't have any idea.

Unidentified: How many years does MIST run?

Hildebrand: It is a one-year project. You probably know a lot more than I do about it.

Unidentified: What is NCAR's involvement?

Unidentified: For MIST, we are supplying a couple of radars and an airplane and a...

Bowles: FAA is supplying the Evans/MIT terminal Doppler capability.

Unidentified: It's about a four-month project over the summer.

Hildebrand: Yes, it is a long field project and involves extensive surface network which NCAR is providing radars, the FAA/MIT Evans radar, NCAR radars, a whole fleet of NASA airplanes. I wouldn't be surprised if the NOAA P-3 gets entrained into that program with its airborne Doppler radar. A good opportunity to fly very close to the ground. You could fly down at a few hundred meters as long as you can convince the pilot to go.

Bowles: NASA has a major funding component that goes through Dodge's office up at HQ, in Space Center. The program is primarily conducted out of Marshall, looking at the cloud physics. We have asked HQ "What relationship could be established to the aeronauatics program?" because we think there is some information we need to transfer out of that onto the aviation side, because we have got a lot of scientists over there, and that hasn't worked out so well. I think we probably need to go back...headquarters. Not that we won't dictate anything, but at least be aware and be the beneficiary of the progress and the data base and...early on for the aeronautics application.

Schlickenmaier: I think you made a particularly good position that you can walk in with those specific requirements and you need a ground clutter data base to be incorporated into the so-called average wind field.

Hildebrand: I could think of a whole list of requirements, including some prototype airborne Doppler data from the P-3 to help us.

Bowles: A question that seems to come to my mind was this sort of methodology that they are talking about: Would this help support the terminal Doppler program? Can we kill a couple of birds with one stone? Those fellows have a ground clutter problem and a moving ground clutter problem. When the airplanes taxi around the airport, fuel trucks running around, does anybody know the answer to that question? Could we be doing something here that may just support this because it could have a spin-off to the TDWR? Or are, in fact, they doing it?

Hildebrand: Consider the synergistic links that need to be explored.

Unidentified: We have been talking about characterization of average...at low altitude, and in order to make the picture complete I know this is...characterization and get some help from aeronautics, from many landings all over the world.

(Unintelligible comment)

Unidentified: I was happy to hear Herb say that he is thinking in terms of having some of that done; that is very important. Actual operational experience in characterizing that...at low altitude, and this work can help...

Unidentified: Where does the problem of mountain wave figure in relation to microbursts? Is ground microburst harder to detect than say a high-altitude mountain wave?

Robertson: Maybe from a meteorological standpoint, Peter might be better to address that question.

Hildebrand: I think the microburst, even if it is dry, the atmospheric part of it has a refractive index gradient that the radar should be able to see. Unfortunately, it has got the ground sitting there right next to it. So, with your lousy airborne radar antenna beam patterns, you tilt your radar up 5, 6, 7 degrees and hope that the edge of your beam catches enough signal to get a response. That is very, very difficult to do. For the mountain wave, you have many cases with almost no fluctuation from anything that the radar can see, and almost no scattering. There is no refractive index gradient, there is no pollution up there, there are some bugs and dust. A LIDAR would be a greal tool. I think radar technology is probably the wrong technology for clear air turbulence.

Staton: The frequencies are too high. If you come down to L-band or UHF, you routinely see these things, because the scale of turbulence is such that you get changes on the scale of a wavelength. If you go towards X-band, they just are not getting that much energy in turbulence scales that size. So it gets tough. You go to even higher frequencies till you are looking at some grainy little aerosols or some kind of particulates that a laser can see.

Lytle: Well, MIST is supposed to be next summer, the data acquisition part. Is there any follow-on planned?

Unidentified: For data acquisition? No, not that I know of.

Hildebrand: I assume that there will be another three years down the road, but at this point, MIST is the next big effort, next summer or next spring.

Staton: Which is the original plan we have? That could be ready for that season?

Unidentified: I just want to make sure there was not any that we did on a time scale that might factor into the planning.

Staton: Peter, you think maybe three years hence there might be?

Hildebrand: I would guess that with the present interest in this type of phenomena, there's a better than 50% chance that we'll have another mission in three or four years, and that seems to be about the time scale between major field experiments, you know. MIST will take place in Huntsville. I think MIST is a great opportunity to this effort, because I think there is a whole bunch of questions that can be basically put down to demands that MIST must meet. How can they have a list of important topics in all the senses and fields for something as important as this and not collect data? That is just another one in our camp. That is just a little more work on our part.

Schlickenmaier: Roland, getting back to the point you brought up about simulation capabilities. To the best of my knowledge, Harry, I don't know of any mass modeling simulation facilities that are available right now to the terminal Doppler weather radar program, which we could make use of. It is an interesting capability at the very least, to be able to establish here a facility for doing numerical modeling of radar systems. And, for our specific application, for modeling both the radar system and modeling of the atmosphere.

Unidentified: To the best of my knowledge, you are not doing any radar system modeling.

Schlickenmaier: No, we're not.

(Two minutes, multi-speaker discussion)

Unidentified: It's not so much radar modeling as it is meteorological modeling: wind field, rain drops, moisture. I'm not sure you are talking about modeling different techniques with radar, or...

Hildebrand: In order to model what a radar would see if it looked for something, you need an accurate description of what the atmosphere is like, and what the ground is like, and a lot of that work has already been done for microbursts, in that you have the best model I ever seen of one. You simply have to add a ground clutter model to that. Well, there is some data and it would be simple to put in a first-order approximation there, and gradually sweep up that part of the description.

Unidentified: You make individual measurements on specific targets: buildings and stuff, for example, then add those discretely to the ground radar model.

Hildebrand: You could put together a very reasonable ground clutter model then; once you have that you could numerically simulate a radar scanning that...

Schlickenmaier: And, the slick part here is that you have almost a full data package, winds included, in the capability to do aircraft simulation, so you know you can actually go through defining the hazards in terms of how the aircraft is going to respond with a pilot...and actually either real time, or you post-process what the radar image would be able to show you, and then not only give you the picture of how the radar is going to perform in a sterile environment, but you can actually tie it to how the airplane responded and how much of a hazard was there during the flight. What I'm hearing from Roland is that once radar simulation capability is brought up to speed, we could probably apply it to some other TDWR application. It provides a neat link, I think--Roland, correct me if I'm wrong--but beyond just having pictures of reflectivity, that can be fed into a radar map model, we can tie to some known performance on how an aircraft is going to respond. It is a nice link between the atmosphere and the radar.

Bowles: I think this is an interesting point that you ought to bring up about turbulence on Friday. I just can't come up with a feel on how much transfer technology will occur here when one guy is working on a big antenna and another guy is working on a small antenna, and one guy is trying to do a scan problem...But regardless of that, it seems to me that if I understand the presentations yesterday correctly, that the key elements here are (1) there aren't going to be enough microburst encounters in an R&D program that you can boot together some hardware and jump right into a flight test program, and say, yep, this works and then tweak, tweak, tweak, you have something that goes. You are going to have to go through a simulation stage where 98% of the tweaking and defining is going to be done, and then take your chances on some kind of white desk effort after that.

Everything from sensor to raw radar design all the way through the pilot's display is most likely going to have to be done through simulation, and the better that simulation is, the more likely you are to have a product that flies at the end. Something that will convince Collins management or whoever, that this is indeed a buyable product. So, I agree that the numerical modeling of the atmosphere is certainly crucial. As I understand it, the only thing that really is missing there is exactly what the microburst does in the lower 200 meters. I think that...his model looks pretty realistic. My reaction to it, I'm not the microburst expert, I just sit here like a microburst expert. That is one key, and I think it is to have the numerical modeling of the atmosphere, and the other key is the numerical modeling of radar, and somebody like Leo is the person who really understands that aspect of things, particularly the problem of ground clutter handling, and that's a whole other area of expertise, and another model, and they link together. Once you develop that model, if you build it right, it's a fairly general model. It can model an airborne radar that scans one way and can model ground-based radar with narrow beam and a different wavelength, different pulse length, or it will scan some other way.

Unidentified: Les, or Leo, who is doing the radar modeling here at Langley, you are?

Britt: Actually, we've done it. We have made a Monte Carlo model of the rain and so forth which we're upgrading to have a look at homogeneous cells and things like that. And, we're going to upgrade it to actually use Roland's model.

Unidentified: So, you guys are already heading down this road that you are talking about. It appears to me that if we were going to say, I'm speaking from a point of view, but really could be at NASA Headquarters on just whoever's pocket we...

Staton: To get one stage closer for seeing a real microburst, we've got to have realistic ground clutter data. So, you've got to fly a radar and look at real ground clutter.

Unidentified: A minute ago, I asked and somebody said we can throw a first-order approximation...

Hildebrand: That's good enough for the modeling development; that is not good enough for the final use of the model to simulate your actual radar, but it is going to take a while to get everything to that point, and so one of the steps is then to collect some real ground clutter data, using whatever radar of opportunity you can grab.

Robertson: No, that is not the thing to do. Maybe--Leo can correct me--but I do not believe it has to be a microburst detecting radar to collect the ground clutter data.

Staton: You are going to need a specific radar type and you have got to decide that that type ought to be your best shot at it before you go get that data.

Robertson: That is true, but it does not have to solve the wind shear problem in order to collect the raw data.

Bowles: You showed us some data yesterday with your radar sitting on the ground, where you suppress clutter. That is a radar of an airborne variety. The difference between what you had with the...

Robertson: What our radar does is either make a mix of recognition, it is either ground clutter or it is not, and if it is ground clutter, it is removed from the display. It does not have any capability to be contaminated by the ground, take it out, and then still preserve the ...The thing that is needed is the detailed model of the ground, because the signature of the ground that we used to recognize and one of the keys in determining the ground and removing it is very complicated. Not only does the ground have a reflectivity characteristic and its spatial distribution and target, but it also has scintillation frequencies that all go along with it, and that gets further compounded by the platform motion, so I think the real data is very important.

Britt: Let me point out too, you can't just take any old radar and go out and get this thing. It has to be instrumented with high data rates, data storage, and that sort of thing, because of the fine points of this clutter. You know clutter is not just neighboring reflectivity. You need the statistsical characteristics, the correlations, and especially if you go to higher frequencies, you need detailed stuff that you can only get from a radar that's got a data acquisition system on it.

Hildebrand: I find it hard to believe that this data set doesn't exist. The problem is simple: is it available, or unavailable because it is classified?

Unidentified: But the other thing is, that somebody saying that the modeling, the analytical, can proceed first because of the time scale involved, you can't wait until you have all of the...because the lead times are too long. Here, you are talking ten years from now it will be too long.

Unidentified: OK, well, it is important that we identify those tasks that are absolutely necessary to get to a workable radar, and put these in parallel rather than in series.

Robertson: Yes, I agree with that totally. The thing that I think, the point that Peter was making is that you can take a first crack at it, the ground clutter, just to get the model working, and get the radar simulation working, but then in order to refine the solution, how do you deal with that? Then the detail of the ground clutter becomes important.

Hildebrand: You need to go through a first design of the radar that probably ignores the ground clutter problem, so you have a generic idea on what it looks like. Find a radar that's roughly like that, and go collect ground clutter data. When you have the second-order model ground clutter in your simulation model, then you start playing this thing around.

Unidentified: You couldn't be making an equivalent statement then about microburst signature. You could make a first-order approximation now based on JAWS data, but you probably need the MIST program to come up with the refinements on that signature, to get some idea how to do the second-order work with the simulation.

Lytle: Well, this is a wind shear detector, not necessarily a microburst detector. So if you can approximate the wind shear and define the wind class, if it covers the classes of wind shear involved then it should be applicable here.

Robertson: I believe that the modeling for the meteorological part of this is much farther along than the ground, and I think there is a lot of catch-up that needs to be done. There is a lot of very high quality field data already taken on the microburst and wind shear cases, but the ground clutter data is lagging.

Lytle: Roy, I would like to say one other thing. You are not talking about a radar; you are talking about a data system and a source of radiation in a particular fashion. You don't need those elements of display and so forth. You're really talking about acquisition of return data process. We are not talking about a radar, per se; we are talking about laboratory instrumentation, collected and put together to form a source of radiation and a way of putting this digitally on tape at a high data rate, so that you have now a return of the clutter information preserved in the raw form. Now, that is different from a radar.

Robertson: Well, not really. I think what you probably chose to do is you probably chose to take a radar where you can get at the IQ output in a form and run a high speed analog data recorder. I don't know, how would you do it?

Staton: Taking a packaged radar and having to go into it, and pull out test points and connecting points is a whole job unto itself that we can really bypass here if we can assemble laboratory equipment to make up the device.

Unidentified: You'd use HP synthesizers, you could use switches...

Hildebrand: If you could, that is what you would want.

Lytle: We looked into using a Collins, which is an airborne source, but no packaged radar has the degree of flexibility that you need; it was designed specifically to a function. Now you may want to later on change your RF modulation. You may want to go linear FM, whatever. So, you want the flexibility, so it is simply a rack of equipment that will serve the point of sourcing and receiving a return signal. It's not a radar.

Hildebrand: I was suggesting a pedestrian low budget.

Unidentified: You showed a schedule yesterday that had hardware that was presently unfunded and...

Staton: And that is this scenario that is being talked about now.

Unidentified: That is what we are talking about right here. So that really is just as critical a point as getting the radar model done.

Staton: Not really, because we can start that right away, and we know that it bears on everything we do in the future. So we are going to do that. We have to do that first. These other things add realism into it as soon as we can, but two and a half years down the road from now, we may be able to start getting real radars. It is not cheap. It's not just a couple of people working on computers. It is a fairly expensive practical project. And if you have design time and enough lead time, but better not start too late, because you can get to that critical place where you stall right there.

Robertson: Everything rests on simulation.

Unidentified: Let me ask you another non-radar question. We are making the assumption at this point that the airborne radar is looking into a ground clutter situation that is totally passive. In order words, if you are going into LaGuardia, you are looking at miles and miles of pavement and you may be going into Pensacola, you are looking at three miles of water with a runway at the end, and it just seems to me that the ground clutter situation would be entirely different. So, from a radar signature point of view, that gives you a big spectrum of ground clutter that you have to deal with, and then you are looking for this little characteristic signature on that big spectrum so you can set up.

Hildebrand: That is a very accurate assessment.

Unidentified: Now, let me ask you this. Is there something that could be done on the ground? I'm thinking of a simple-minded thing like a corner reflector or something at the runway that could now give you a big spike from the signal at the place where you are trying to suppress clutter or something like that, that would allow you to do a very artistic job on suppression and now look for a signal, and say something like this: if we could put something on the ground that is relatively inexpensive, then we could do that at all 600 air carrier airports, no problem with that. That would help the airborne radar functions. Does that change the picture any?

Unidentified: It would give you range to the end of the runway.

Unidentified: It would give you speed.

Lytle: Yes, but you should be able to get that anyway. You have got your beam that spreads out and your sidelobes that give you velocity over the whole spectrum, so at one point straight ahead...

Staton: Yes, but that one point dominates, then you can get that speed precisely.

Hildebrand: I think that the value of this suggestion is that it is outside the normal realm of thinking of how you design a radar to measure something, and I don't know how you use that idea, but I suspect that it is an idea that should be considered on designing the whole thing.

Unidentified: Well, it is just a spike in the returned signal. A spike can give you the velocity of the aircraft and the distance between you and that corner reflector.

Unidentified: Is there something that we could do at the airport that would help the function of this radar?

Robertson: That is a neat idea to explore. I can't answer the question of how it might be utilized, but that's certainly another dimension that could be considered. I don't know the answer to the question right now, but that is a good idea. Another thing might be instead of the radar transmitting down and looking at a reflected signal, is there some kind of inexpensive transmitter that we could put right at the threshold of the runway that looks up the approach path? It is nothing but a cheap transmitter, and now you have a receiver in the airplane.

Staton: Well, you might as well put a...screen on it, and send up the terminal Doppler radar display there.

Unidentified: It seems to me that the thing that drives cost way up in the radar is not simply transmitting the signal out, it's taking out a very low energy reflected signal and doing a lot of processing on that signal and trying to turn it into something we humans can understand. That is why I'm saying we couldn't afford it for something like that at 600 airports. But, if you add a simple transmitter, but maybe the whole thing is stupid, but is there something other than radar?

Britt: Are we just trading things off here, and just buying a new bag of worms?

Unidentified: A bag of worms is a bag of worms, that is all I've got to say, but if it keeps airplanes from running into the ground because of wind shear, you know, then that is another whole question. Sure, no matter what we do, I mean, whether you are talking about transponders or satellite surveillance, or anything else, it all ends up in chaos sooner or later. I guess what I'm saying here is, if there is something simple we could do to make the whole problem a lot simpler, then that should not be necessarily discarded. An airborne system that has a minor dependency upon something on the ground to increase its probability of functioning properly is not necessarily out of the picture. The idea here is that there is certainly room for a lot of innovative thinking.

Unidentified: One of the big problems, as I see it, is that you need to have a local oscillator to heterodyne down this ground signal to a zero signal so they can be easily sorted out. That could maybe help the problem, but you would have a ground signal there already. The spectrum would be quite narrow.

Robertson: That's true. If there is any tracking system, that will be a real benefit. There is extremely large variation; you know you might have an approach like ours in the middle of an over water approach, like SEATAC, or over a bay, places like that or Los Angeles, with traffic all over. Memphis, Tennessee, we have a ground base installation that has a little north-south line of turbulence about eight miles long, about 7 to 9 o'clock in the morning and 4:30 in the afternoon, so it does have a very important effect because of traffic and other things. So, all of that goes into making a wide range of ground clutter situations.

Unidentified: In other areas, navigation in particular, the FAA is looking very much now at ways of creating a dependency with the local airport that might improve the functioning of the system, and LORAN-C and GPS are areas where we are talking about putting another receiver at the airport to take out the errors of signals propagating through the atmosphere.

Unidentified: What are some of the applications here for LORAN-C?

Unidentified: They are looking at differential navigation, defense surveillance. There are all kinds of areas where there are a lot of precedents for this type of thing.

Bowles: Can I ask you a question? In a case of fixed objects on the ground, a radar that is moving with a known speed, do I not know roughly what that translates into where the frequency is spiking?

(Multiple speakers, simultaneous comments)

Staton: Every time you approach, the speed is a little bit different. So you can't use a fixed one, you have to find where that is.

Hay: You know on one of the discussions of the flight on the screen, I saw a notation that ground clutter is a narrow-band signal and turbulence was a wide-band signal. So I would almost think that you could filter out the ground clutter by putting it through a notch filter and what lies outside of it is the turbulence.

Staton: You would have to place the notch?

Unidentified: Right, and hopefully, that is your zero frequency.

Hay: Well, it can't be near zero frequency.

Unidentified: Well, it's much easier if it is. Then you heterodyne it out.

Hay: You are going to heterodyne it at the speed that your airplane is moving. So if you know what the airplane speed is, you know you could put that into your device and use it. Nevertheless, it seems to me that you could filter out the ground clutter and instead of trying to black out everything because there is a great big signal there, just blank out the frequency spectrum that contains the ground clutter. Now a guy could say, well, if the air isn't moving, that is the same speed as your ground clutter, but I could argue that that could mean that is not a problem, so if you filter out the return from the nonmoving air, why, you haven't lost anything. It is the turbulence, though, that gives you the wide spectrum that you want to preserve and that will stay outside the filter.

Britt: I think you got the ground clutter all the way from zero to whatever airplane speed is because of the antenna looking out sideways.

Hay: Right; however, one nice thing is you can make the use of range gating. So you can forget about sidelobes that are hitting the ground closer. Like near vertical, because in that situation, you get all the frequencies from zero frequency Doppler, meaning zero speed, to the maximum speed essentially to the range in what you are looking at. Now, all of these being at shorter range means you can blank those out by range gating, so now you have to figure out a ring around the airplane which is at the same range that you have to be looking forward, and these sidelobes of course have got to be down, so that helps you right there.

Lytle: Yes, but you can't range gate necessarily if you are coming in low; distance to the ground is closer probably than the distance that you want to look ahead.

Hay: That is what your range gate is for. When you range gate, you get rid of all the stuff closer.

Lytle: You get energy from straight down all along the ground.

Hay: But those all come before you open up your range gates. So you don't see them.

Lytle: Then you are only going to look at a far distance, one range gate at a far distance.

Hay: One range gate at a time. Well, that's the way the Collins system works. You know you can't make the map unless you say what is turbulence here, what is the turbulence here, what is a turbulence here. So, while you are looking at the turbulence here, you key out everything else.

Hildebrand: I think what he is really saying is that ground clutter suppression should not be a totally intractable problem. I think it is also true that it can be a tough problem that we are not going to solve here, and that we could probably more productively come up with a plan for how to solve this whole problem. We need an approach to the massive problem here, not just the ground clutter problem.

Hay: Seems like ground clutter is the major problem.

Hildebrand: A significant problem, but not the major problem.

Hay: What is bigger than the ground clutter problem?

Hildebrand: The sensor looking out in front of your plane to give us some intelligence over the full scanning of...if the problems are a little simpler, than maybe achievable earlier by looking at those few cells in front of the flight path.

Hay: The point is that for every range you have looked at, you know you have a different Doppler component, because the angle between the angle you're looking at and your flight path vector is different. But you can range gate, so that limits the amounts of range of clutter you are looking at, and then you can frequency filter to get rid of the range of velocity you were looking at. What is left over, that is the turbulence.

Hildebrand: There is something important going on I sense here, and there seems to be some very innovative thinking going on and exchanges between people who know what they are talking about. The important thing is that maybe this is the meat for a good workshop that you could hold shortly on ground clutter suppression and some of these people from these black programs could come in who have been working with these problems with look-down, shoot-down radars there...

Staton: If they are black programs, they will only listen when they get here.

Hildebrand: But there are a number of people who have done ground clutter before. We may benefit from their experience.

Unidentified: Peter is right. I don't think you can solve the problem in this meeting today. But the kind of exchanges going on here really give me hope that the ground clutter suppression problem is really tractable. You may be getting people who are here who know what they are talking about, plus some people who are working this problem on the military side. Could be a very good workshop.

Staton: I think we need to do some homework before we have that workshop. I don't want to go through another saession like this, where we are talking around the problem, and haven't gotten to the meat. So, we need some time to go by, after the first of the year.

Schlickenmaier: Oh, yeah, I wasn't even trying to suggest a time scale. I think you are right.

(Unintelligible)

Unidentified: Are you talking about system requirements? I think it is important that we understand whether you are talking about requirements for this experimental system that needs to be put together to collect the ground clutter data that then comes, or simulation.

Schlickenmaier: (Unintelligible)

Unidentified: I guess you would call that radar system capability. That's a working prototype of a wind shear detection and avoidance system that you are talking about.

(Unintelligible)

Bowles: I guess the question you are asking is based on the assumption that the moving ground clutter problem was solved; we make the assumption that the hardware can be built. How would we use the capability in an aviation kind of way?

Schlickenmaier: What are we using it for? What kind of concepts are we working on?

Unidentified: You are talking about the operational sensors.

Schlickenmaier: Well, not quite to the point to that meaning, but yes.

Unidentified: I guess what I'm getting at is, system requirements in the technical sense are being partly generated, it seems to me at this point, because the simulation program based on the data that is collected and so forth, is what will really drive the answers there.

Schlickenmaier: The specifics of what the antenna sizing is, what the frequency is, what the processing is that is involved in ground clutter and how you do the processing--these details can be worked out later. But what I see is more global local system requirements that look at what kind of range, what kind of proposed operation are we looking at. Were you really talking about looking at a full scan with all sorts of contours? Or are we talking about feeding an airborne Doppler with a radar-type airborne wind shear detection and avoidance package, where you have got it on radar, with information in terms of hypothetical...some added number of points in front of you on the flight path of the airplane, and those velocity curves, feeding into something called a hazard.

Now granted, you know both of these are going to take a lot to get to. In this case, there is some fair amount of ground clutter suppression that needs to be done--some fair understanding of fairly detailed work, how you do the scanning strategy, but I'm trying to back it off from the pilot point of view. Which one is going to give us the best information for the flight crew?

Unidentified: I understand what you are saying, and I think we are in the wrong meeting to address that question right now. Thinking back to the Collins problem where they were working on the turbulence detection mode of their radar, and as I understood what you said, the question came up, where do we set up our threshold for turning on the magenta? You got that by going to your airline people and saying, where do we set these thresholds? You have to have an understanding of what amount of gusts constituted an upset to passengers, and what amount of gusts constituted a hazard to the structure of the airplane.

But, you don't go to radar engineers and ask them that. You go to other people.

Schlickenmaier: Are we talking about a system that conforms with require ments in the cockpit, or are we talking about feeding information into a hazard computer with a flight status monitor? When things get out of bounds, there's a go/no-go light.

Unidentified: Yes, I guess what I'm saying is that question is something that needs to be addressed in a forum that includes quite technical people and that input becomes a design requirement for the kind of people who are here.

Unidentified: For a display that sounds very attractive where you contoured on the levels of shear; it may be, however, that the airline engineering people would say no, we really don't want that, because we would be providing a display to the pilot that is going to allow him to make decisions on whether he has got a flyable shear or not. He may be using this thing as a penetration tool rather than an avoidance tool. We don't want that. Wind shears above X number of knots per foot are known hazards; they are known to be infrequent, and the number of go-arounds that we would get as a result of just giving the guy a go-around light are so few that we really don't want him to use this as a penetration tool. You only want a light that turns on if it is a go-around. What I'm trying to say is that if all you need is the go/no-go light, then that sets one level of requirements for the designer. If you need to be able to contour on various wind shear levels, that sets another design requirement, how accurate, etc. So it seems to me that the box you want to fill up there is certainly an important box and you need to get together with AFO 210 people, the ATA people, and you know all the right people. Have them do some thinking about how an airborne wind shear detector ought to function, and what ought to be displayed for the pilots. How accurately do they need to know things? How much lead time do they think they need for a go-around situation? And then let that become a requirement that you can pass back to the design people.

Unidentified: This may be a hard one to answer--doing this package, doing the visual presentation of data of some sort, at some kind of mean level with reflectivity data overlays with moving map displays.

Unidentified: What do you see as the timeline for this?

Schlickenmaier: Well, here's what we see as the timeline to provide some information for this version; there is no particular difference. The amount of work is roughly the same, and I know it from talking with two friends up in the Northwest Mountain region. Then they come back and say, well, why don't you ask the radar guys about it?

Unidentified: If the question you are asking in your other box is, what are the radar system capabilities, then I think you have got the right people here to give you a way, based on what you know now. What can we achieve with 50-50 chance, what level of performance do you think is achievable with only a 20% probability or 97% probability? That box, I think you can fill with these people.

Unidentified: There may be two boxes, depending on the system. They need to somehow scope the people who are going to make the request what those requirements are anyway. I only wanted to indicate there is indeed some progress that has been going on for some time here at NASA, out of which come some requirements for dual frequency agility, where you probably need to display sectors to give what I call advisory-type data, or could we get some really accurate data from radar that would help us out, and we do indeed have the concept where if you radar people can give us the winds ahead of the airplane, we can use those winds to divide the power in a very advantageous way. The fact is we design path-in-the-sky and tunnel-in-the-sky displays that become colored, red or yellow in accordance with what the radar sees ahead of the airplane, in a way of wind changes. That is what the airplane is afraid of. The rate of change of the wind that it is going to see. So if you radar fellows, sensor people, can give us wind changes ahead of the airplane in its path, whether it is straight or curved, that is what we are after. We have means of displaying it. You are asking for requirements that the system has on the sensor. What should your sensor be providing? I say give us the wind velocity or rate of change of wind ahead of the airplane, in the path.

Unidentified: All of the operators that I have dealt with, over here, and overseas, as well as ATA, have said that the first level of...

(Unintelligible)

Am I going into an area of increasing potential performance, or into an area of decreasing potential performance? That's my point.

Hildebrand: I think if I were to try to design this radar, I wouldn't want to try to get in on the question, how do you decide what you show the pilot? What I can talk about is what kind of raw data could I display? What are the types of derived displays that I can I think of putting out, and there are a lot of people working on that. You apply all of those ideas, but other things I would also think of in doing this are the limitation on where you have to look. Given 2000-foot altitude, 3-degree glide slope, and a maximum velocity in any direction of a wind shear of 20 meters per second, they are all-in-all reasonable numbers, and airspeed of about 150 meters per second. You have to scan 15 degrees on each side of a flight path, and if you do that, you are not going to miss seeing anything that is going to hit you, providing it doesn't go faster than 20 meters per second. Now all of those numbers are debatable, but the fact is that they are not unreasonable numbers. The fact is you could define design criteria such as those and limit where the radar has to look and where it has to do this specific job, and I think that sets bounds on this whole problem.

Robertson: From my point of view, the fundamental question is how to extract the raw data, and then given that, raw data using a radar or whatever technique that is most applicable then, your decisions can be made to either display it in its raw form, or maybe some intermediate forms such as increasing or decreasing the performance, or all the way reduced to a go/no-go decision. The farther you go on that path, the more difficult it is. If it's in its raw form, then the false alarm question can always be overridden by the pilot's judgment, but the further downstream you go, then it plays the false alarm case and the burden is more securely in the hardware. I think the question I can best address at this point is the extraction of the raw data to begin with, and I think there are a lot of people who have expertise in guiding how best to prevent it. I really don't see a difference in how we approach the basic problem at least on the surface. I think the technical issues that need to be addressed are very significant, and I might like to suggest that we would modify what those tasks are, as far as the technical problems, and maybe lodge some.

Staton: One of the big things we have got to decide is whether we can commit to assembling a new scatterometer (to avoid Carroll Lytle's distaste for the word radar). We're going to assemble the hardware to do that function--whether we can commit to doing that right away or whether we're going to stay in this all-important study phase for one more year, and then commit to it. We are always a year away from having any hardware in hand. So, if we do wait, we wait one more year.

Robertson: I think the efforts we have talked about here in terms of defining simulation to the models are fundamental to every other approach regarding the plays and procedures and how the information will be used. As we learn more about the sensing part of the problem, then that may have a very direct bearing on what is practical or desirable.

(Unintelligible)

Staton: We ought to make it clear for everybody concerned that the hardware that I was just talking about is not the prototypical instrument; this is just something to quantify ground clutter and wind of opportunity.

Unidentified: The prototype instrument has to come much further downstream. After the simulation studies are done, sort of optimize the system parameters. In your presentation yesterday, Leo, maybe I missed it, but I thought your schedule was more oriented around the assembly of this hardware and the need for the scatterometer and didn't include a lot of information about the development of the radar system model.

Staton: It was implicit; I just didn't put down milestones. That work is presently funded at a certain level, and is going ahead.

Unidentified: That's OAST-funded, isn't it?

Staton: Well, not completely, because we don't have OAST money to build any hardware. So, this is a schedule based on no increased funding during this coming year for hardware.

Unidentified: I guess your second point is the one we've been discussing here.

Unidentified: What I was thinking was when you say the wide basis for hardware design, I was thinking of the hardware being the scatterometer hardware.

Staton: Yeah, that is what I'm talking about. You are creating a set of hardware, a scatterometer that is going to collect the ground clutter data that feeds the simulation study which now provides the basis for hardware design for a prototype system.

Staton: It feeds back into the simulation.

Unidentified: It's then really two sets of hardware we're talking about.

Staton: The computer work needs to be done in order to be able to commit to that range of performance that you want your scatterometer at. You can't do everything for everybody.

Bowles: I hate to do it to you. Herb, let me ask you a question. Hardware is designed to do what?

Staton: To gather primarily real airborne look-down ground clutter at airport environments.

Bowles: Not a hardware design that is charging at a conceptual candidate detection, warning, and avoidance system. Some part of that, because when you gather this sort of data, it's got to be in a context that gives you a best shot at what the ultimate is going to be.

Bowles: Right.

Robertson: From that viewpoint, it is.

Unidentified: So what we are going through, in essence here, the timeline we need to send Herb back a bit, is that you go through a simulation modeling stage that allows you to optimize the design of your scatterometer towards what you think are the characteristics of your end-product prototype system. Then, you go through a hardware stage where you actually collect your data. Parallel with that, the radar model and the atmospheric numerical model are being created, which are now the things you are going to embed all that data in once you collect it, with that scatterometer hardware. So, there is a parallel modeling and simulation path that is going on.

Staton: That is farther along, as I see it right now. Roland has a lot of stuff we can bring in wholesale.

Unidentified: Right; then those two coming to confluence somewhere, with data from that plus the data from perhaps MIST and some of these other programs, now keys in to this one giant simulation model that allows us to optimize parameters for a third type system--hardware that maybe one of the manufacturers will build, that can then be testable in the flight test environment.

Robertson: I think if we implement the steps that you just outlined, we will have taken a huge step toward the solution.

Unidentified: Now, if I might be so bold to suggest this, that path does not jump out at me from your chart. Well, the thing we are up against here is there is a lot of momentum, frankly, that has developed towards ground-base radars, and these kinds of things, and if you want to have a viable well-funded airborne radar effort, it has got to be clear that there is some light at the end of the tunnel; some hope of coming out with a system; some clear path that leads us to the point where we have a protytype system. There are a lot of people like me who are non-radar guys, that just think that you can skip these intermediate stages; that somewhere in some lab there is some genius that can throw a bunch of hardware together and skip right into the prototype warning system. That is what they are looking for--looking for someone to walk in and tell them that, and they are going to give him a big wad of money and send him off to do it.

Campbell: What you have got to recognize is that this is still a research project, and there has been a lot of rhetoric with respect to all that needs to be done. And, if a lot of people who have been proposing programs in the past, and the financing hasn't been coming through to support those activities, and now, you know, it's just ludicrous to think that now you can say OK, skip these intermediate steps and come in and give me a grand slam homer and win the game. We all know that that cannot be promised.

Unidentified: We don't all know that that can't be promised. I think there are a lot of people that are grasping for straws. You know, when an airplane hits the ground, a lot of people get excited, and a lot of people are looking for a quick solution. Now, Cliff made the point yesterday that there needs to be a lot of intermediate output from a program; that you can't wait till you have your best shot and then present it all at one time. And that is where you need a lot of interaction between who might be the end customer for something like this and say, tell me what you would consider an optimum design, and tell me what you think is the minimum acceptable and you can sort of design your programs so you output along the way with things that meet this minimum acceptable standard while you are working towards...

Hildebrand: One of the things that can be interjected is that there are airborne Doppler radars now--the search radar on the P3, the Collins weather radar which, with some modification, could be drafted for a very minimal approach to this kind of problem. I'm going to be building one. It is not going to be designed or optimized to this problem. All of these radars in one way or another demonstrate feasibility in seeing some of these phenomena, and these can provide some sort of interim prototype steps, but they will also show both the value of this, and the value of continuing the deliberate approach because these things won't work all the time. They teach something; they are an important part of the development program--both as a tantalization and as confirmation for the deliberate approach, and I think that that's one way of showing that there is a light at the end of the tunnel.

Unidentified: And I think that is one half of what you need. If you are the guy providing the money, you need for somebody to walk in and say, not just myself, but a whole bunch of us, all think you are slightly near the end of this tunnel. And the second element you need is, here is a clear path of how we're going to get there and here's how many bucks and here is where the intermediate outputs are to the best of our knowledge at this point in time. This meeting I sense that the light is getting into the tunnel. I don't know how you can sit here and not get that feeling. What is missing right now is this clear path that shows what we've discussed here today. It doesn't jump out at me from the chart.

Staton: This is not the chart. I do have some charts that have most of the items on them that you mentioned.

Unidentified: Well, if you could pull that out Friday morning, I think that would be a big step in the right direction towards getting the money that is necessary to make something like this to get off the ground.

Staton: There is a problem with it. It takes money to get the hardware. It takes money up front to order things so they could be delivered in twelve to fourteen months. That's what it takes for many of these major components. You don't have the money to do that within this current fiscal year; but start, though, the things you know you must have or we won't be ready.

Unidentified: You know you can show your path in terms of months from start date, for example, you know, or months from go-ahead, or whatever, but the point is the guy we are going to be briefing Friday is, at least from FAA point of view, one of the guys who holds the purse strings for giving money, and of course you've got your guys and NSSL has their people, and money can come from a lot of sources. But, I think it would be to our collective benefit to be able to show the path that we sort of outlined here and really give this guy an upbeat kind of presentation about how we can get this program going, and here's the path that gets you there, and whenever you decide to loosen the purse strings you can kick this whole process off.

Campbell: How much do these cost?

Bowles: Who will cost those out?

Campbell: We could say, please give us a resource estimate.

Robertson: You could say that there are multiple facets, or agencies, involved here.

Schlickenmaier: The point I was getting from you, Tom and Leo, was that for this first cut, you are looking for how we could get some immediate financial relief in order to anticipate some of those early budget items. We are roughly covering FY 86, and for FY 86 we are still talking of stopgap projects at this point, because I'm not going to be in the budget cycle until 87 with this program. At that point, Neal is still with FY 86 money, holding the purse strings.

Campbell: There is a possibility for reprogramming '86 funding. The only reason I'm sitting in this meeting today is because the guy asked me the question, what can we do to accelerate this work, number one, and number two, is work accelerated or are we throwing money down a rat hole with airborne Doppler radar. I guess that is why I asked a lot of questions: Is this a rat hole or not a rat hole? I'm going away with a strong sense that it is not a rat hole.

Fedors: There is always a certain amount of risk involved. We may get down to the end in three or four years, and it may be that some element totally falls apart, but right now there is light at the end of the tunnel. It may never be there. You can't guarantee a guy that you're going to deliver something.

Schlickenmaier: I'm not asking for that project; what I'm asking for is I need some sort of logical sequence of what we are going to head for, and what roughly with. It is our zeroth-order guess as to what the task-to-task relationships might be--what kind of products we might be looking at, and for this one particular case, in terms of '86, can we accelerate it? If we can, what might it cost us to aid in that? I think we are mature enough to know, yes, there is a technical risk that may walk up at the end of this project and absolutely chunk a big part of this away.

Hildebrand: I think you made an important first step with a diagram up there that has got a whole bunch of elements on it. A lot of the elements can be carried out right here; some of those elements elsewhere. I think some level of refinement of that could possibly be done here and you, others and smaller groups are going to have to refine that further for a much more formal and permanent plan of action. But, right there is a beginning of a plan.

Campbell: How can you accelerate a plan when issues are ground clutter, how you have look-up mode, and flying and all of that jazz, and you accelerate things to participate in that next spring, and identify those tasks, cost them out. A lot of things could be done.

Unidentified: Not only do you need a good pairing shown in your presentation. If there are dependencies on somebody else, you just need to make those clear. I go back to how this whole thing got started. They guy who kicked this off was your own man at NASA Headquarters--Lee Holcomb. He sent the message to Neal four or five days after the Delta accident, and said, what can we do to help you guys in this wind shear area? That's when Neal started making calls and asking questions and a meeting was set up between you two guys to talk about how things could be accelerated, and he'll be in the meeting Friday, also. All the indicators at this point are saying that those people are behind you also; they're just waiting for you to tell them what you need.

Bowles: The matter of the Holcomb thing, where he specifically told me that they're anxious to understand the full impact of what you would like in terms of support so we could accommodate that in the upcoming budget if you went that far--they are also going to want to accommodate next month a special topic review on the instrument. It seems to be that Friday has a very specific objective. The meeting Friday ought to come out with a very specific positive objective--a word to convince Neal that though there are a lot of issues and some technical difficulties, that the airborne option is something that he could speak to with confidence as a supplement to his terminal Doppler program and the enhanced LLWAS. If you could put it in that context, it gives him confidence to keep that dialogue with OAST going. It goes on the record in front of the Congress that that is creditable and that is what he needs at this point. That is only getting the foot in the door. But you can't do a program until you get the foot in the door. How this relates out to MIST or JAWS or...we should realize Wallops either. That can be done in the context of the integrated program--and will be established as a directive out of the integrated programs.

(Unintelligible)

Campbell: What if it is said we really have to get our act together, because this whole thing is evolving. We're like the end of the tail here because I have been led to believe that this meeting with Neal Blake is going to be nothing but a briefing session. This is the way we got the message--the fact that we want Leo up there, we were going to sit down and just brief Neal. Now it is starting to be a very critical meeting, and it can be counterproductive in that if we don't do a very good job, going up there and putting this organized plan together, this road map with all the bullets and all the participation, and cost that thing out and also show him not only that there is light at the end of the tunnel, but it is not going to be a freight train, and we have a little more work to do between now and then. Maybe I'm dramatizing this whole thing, I don't know, I'm getting a little nervous...

(Unintelligible)

Bowles: Jerry was at the other meeting. He sensed the momentum and the direction in which it was headed. The way this came up was, in the rela tionship, we went up two weeks ago, said, this is what we propose to you as a part, in a contribution, to the national plan. You guys are straight. If you look at it very carefully, any one element can disappear out of that program, but there's a remnant program left. Jerry is keeping his options open right now. Airborne radar is one component.

Staton: When we put this plan together, we never said this is a Langley proposal. If it is accepted, we will do this. This was always a possible future and the whole thing is not going through Langley, as you all know. It's a possible scenario.

Bowles: It was set up by the two directors, that said, this is what we will propose to support the National Integrated Effort. Not at level three planning. We took the opportunity to go up and verbally brief that to Neal. Out of that came a specific set of questions about airborne radar technology options.

Staton: Okay, well, I have a problem with two directors co-assigning it, and the hardware's going to be built and the experiment conducted in a third directorate, and then signed off by somebody else.

Bowles: Well, that has been a changing situation.

Campbell: Maybe we have got this off course now. Maybe I made it that way, so I apologize. Maybe we need more talk about how we're going to plan for this meeting. Let's get back to what Herb wants done.

Schlickenmaier: Well, you're not too far off track.

Robertson: I would like to draft kind of a timeline and categorize the tasks we've all been talking about, and the three separate parallel paths that might be conducted. And, end up with the end result of a certified box.

Verstynen: Tom, I think it is important to understand that at this point in time, nobody is trying to make anybody make, commit themself to program it, at the management level or the technical level or anything else.

Campbell: No, I understand that, Harry.

Verstynen: All he was looking for was, is it a rat hole, or is it not a rat hole.

(Unintelligible comments)

Verstynen: One of the whole litany of things that Roland presented that day, that were included in our submission to Cliff's plan, he seemed to understand and be comfortable with almost all of it, and the man is extremely well versed in radar technology.

(Unintelligible)

Campbell: But, he wants to be told that there will be an airborne Doppler radar or a microburst detector on board an airplane within five years.

Verstynen: What I'm trying to say from the whole litany of things he was briefed on, the one he seems to me to be most uncomfortable with was the airborne Doppler technology.

Unidentified: He has always had a hang-up on it.

Hay: That is the way to put it, he has always had a hang-up on it. It isn't a bias. He has a problem with it. Until now, nobody has sat down and gone A, B, C, D, E, and said ah, E, the one that's used the most, OK, it will work. When you go up and say that, just like Roland, that was an incredibly fine briefing Roland gave him that day, and it really did more for us in the wind shear program.

Verstynen: So, the man is technically uncomfortable with that. I think that if he could have been sitting here today, there would be no reason to give him the briefing because he would have heard all of this, he would feel comfortable with what is about to happen, and no one will have committed to doing a program or anything like that. But the man could at least go away and say, if we all agree to garner up the resources and the manpower and all that it takes to make a bureaucratic program work, then I'm confident that this one will not come back and haunt me. At least there is no higher risk here than in any other program.

Hay: Harry, let me insert one other thing, if I may. You are absolutely right in what you said here, but Neal has said it was going to be an airborne program. No question. It is going to happen. There is no question that there is going to be an airborne program coming from an airborne Doppler radar type, and this meeting Friday is not going to change that one way or another. Second thing that is going to happen is all other airborne sensors are going to be examined and in situ devices are going to be examined as well. We've got Boeing coming right along right now for certification; Sperry is about to get approval on theirs, the first instrument certificated for actual wind shear avoidance, isn't that correct?

(Unintelligible)

Hay: All of these things are going to happen, and there will not be a decision known under any circumstances on Friday. It will be how well we go through it, and how clearly it is understood, and how to find the direction at that point of success, and only people such as you, Tom, Leo and the troops that are in this room can provide that kind of input, and they are more than capable of providing it and providing it very well.

Verstynen: Let me ask you a question. Is it not true that Neal goes on the Hill on October 2nd and at that point in time he is likely to be questioned on how the level of confidence that he assigns to these guys with regard to prospects of airborne Doppler technology could have an effect on what they decide with respect to...

Hay: Yes, he goes to the Hill on October 2nd. The effect is how well his briefing comes off, and Neal is one of the smartest guys I ever worked with in my life, technically. The individual is incredible. You are giving a three-and-a-half-inch report that you called him up? He said he reviewed it, didn't he in the meeting the other day, and he repeated everything you have got in that report. He read it, he consumed it, and he is committed, and what he wants you to do is sit down and look you in the eye and look Leo in the eye and say, now how should I feel about this, guys? And have you go through the technical steps, which he's more than confident to pick up and follow you on, and you guys are more than capable of giving it to him.

Unidentified: I thank you.

Verstynen: Don't undersell yourself. I think that essentially the airborne Doppler development is moving in the direction of a certifiable production airline system as opposed to a research system. But, the centroid of that work is here.

Hay: Let's give the devil his due: if I were to say that dozens of times that you and I sat down and spent a little time going round and round and you're confident and this has helped direct this integrated program plan that we put together, then I agree with Harry that the centroid is probably here, but there is a lot of good work you guys have done.

Hildebrand: Now you should feel that I don't have any problem with the center of development of the airborne Doppler radar being here for this problem. I'm going to build a research radar, but I don't feel any competitiveness at all towards this problem, and my primary interest here is to assist that if I can. We're thinking about and then I suggested to Roy that we could put another box up there about prototyping sensors, because I think I could help with the useful role there for showing what you could see with a radar that is not optimized for this job, but can do a pretty good job. I think I can help there, and I would like to do that, but you can count on my full support for the program to be based here. It's not my interest, or my job to build to that radar.

Robertson: In going through this discussion the last couple of days, it appears that the various activities follow three areas, please correct, and help me build on this model. I'm trying to put together a skeleton and try to build on what we have been talking about. One of them, the central element in a lot of this is the simulation, the development of the models and the total end-to-end simulation capability. The top line represents what I consider the sensor development. This would be the path to the end sensor that might end up being the wind shear detector. The bottom one is a supplementary data collection process, primarily to get the ground clutter data. Then time goes along the axis on the bottom, so maybe some boxes that are missing here and some hurdles along the way. But fundamentally, the way I see it is that right now, Roland has some very, very sophisticated atmospheric models that he has worked on. The radar models exist; however, we need to get them pulled in from the places where they reside and get them combined with the weather and atmospheric models that Roland put together. This would give us a first-cut atmospheric/radar sensor simulation capability which will take a swag at the ground clutter as it exists and put together a first cut. I'm going to ignore this box for the moment, and I'll come back to it. This first-cut model now is based on Roland's existing atmospheric model with a slash at the ground clutter. That is something we can come up with or that could be achieved in the near term. That could be used to evaluate the feasibility of the airborne sensor. What are the outside boundaries we can expect this system to be able to overcome? As a parallel path, there's a very crucial need to embellish this atmospheric and ground clutter model with more realistic data, so that is a fairly long time process in itself. That Leo has been proposing, so at the immediate time then, hardware procurement can be begun or as soon as that has evolved to the point where you understood well enough what the hardware requirements are. Then, in parallel with the first-cut model could begin the activity of ground clutter with a real ground clutter model for the raw data collection. Now at that point we have the basis to build a refined detailed atmospheric radar simulation capability. Now that is the real tool that it's going to take to develop the algorithm, the process, the system, the detection techniques for the sensor. Now this model will be the workaday tool that our engineers will use to design the wind shear sensor. So, that feeds in with the feasibility studies and the real time model that then results in the sensor development. That is where the real work takes place. Now, drawing from our automatic landing experience that I talked about yesterday, the primary testing that will...sensor will be done in the simulation, and the function of the real time flight test program will be to validate the models in the simulation techniques. So, now the sensor development takes place, we have a sensor flight test program, and then that feeds back to simulate the wind shear model that we have been using in the radar system. When those two results combine together, we now have the basis to begin the certification activity of the sensor. So, the analytical people, Roland and the NASA folks, have a good handle on the model and its techniques. Leo, I'm just saying names, because these are the people who I immediately attach to these jobs, they come to mind, but in terms of the fundamental hardware raw data collection that is needed to refine this model, that activity can start immediately, and this gives us as a manufacturer, and Peter, and people who are playing at the Doppler radar business are placed to play around with ideas. You can go back and start soldering circuits together and see what we can do. Just maybe a tagalong with the MIST program and side activities to test various ideas out as we're going along. What this box means by prototypes using existing sensors, there is a big baseline capability existing in the research radars in our commercial products that are manufactured. But, I think that these paths get everyone home to work and we're all working in a parallel effort. Does this seem like a reasonable way to go?

Verstynen: That is an exact diagram of basically what was going through my mind a few minutes ago. I think that is the right thing. I do have one or two comments. I would like to see a flow chart like that show where the inputs are needed from other programs upon which we would be dependent, like MIST or JAWS or something like that. For example, nowhere in your flow chart does it show that we really need a refined model of the wind shear itself or the microburst, or however you want to refer to it, and that would come from a program that would be outside of the scope of this, but maybe you would want to put a dotted line around that, and say this is the program we're looking to fund, and ends up with a sensor, but there are these other inputs that come across the boundary.

Campbell: Too many boxes across the bottom that feed the data collection input and ground clutter...We could add a box for ground look-up.

Staton: Just to the right of the one on the bottom line. It is really right after the ground clutter data collection. We could take some same radar and look from the ground and look up as part of MIST-2 or whatever.

C-2

Hildebrand: I also think that maybe off to the left of your chart, before the atmospheric model, we should put down JAWS and MIST...and they come in to the left of the atmospheric model.

Robertson: For the present, I think I might leave the embellishments on the chart, but I think we can show this as a continuation of existing programs and work. There need to be some inputs from the refined atmospheric models.

Hay: To my way of thinking, there's something missing all the way over there to the left. I have been hearing all the talks about how you would sense with airborne sensor, but it has not become clear to me on why do we need an airborne sensor--the point being that for the characterization of the wind shear, we've all been talking that we need it in the terminal phase, where you land at the airport. I could argue that if the airport has a radar that can determine the wind shear, then you can have all the sophistication you want and have a radar at every airport, but you wouldn't have to carry around a radar in every single airplane just to determine this.

Unidentified: How many airports would you put the radar on?

Hay: Well, wherever we landed..

(Unintelligible)

Unidentified: There are 700 air carrier airports right now.

Hay: Then, put them on 700 airports!

Unidentified: Well, let's see, at 4 million dollars each...

Hay: Now, wait a minute. How much are you paying for this radar right here? There are a lot more airplanes than airports!

Unidentified: The whole purpose is not that it is a systems approach, so that the whole program can be gracefully degraded and still give useful information. I think I'm using your terms, Roland.

Hay: I guess I miss the point. Are you saying that if the airport radar doesn't work then you have this as a backup?

Bowles: It supplements TDWR, where TDWR exists.

Hay: Why do you need the supplement if the ground station works?

Bowles: That is the public policy issue. Who pays? From the technical point of view, I think you can argue convincingly that there are advantages to the airborne wind shear radar detection capability, because there are going to be a lot of airports not protected by the TDWR under the current outlook. That is public policy. That's OMB policy. We can't determine that here.

Unidentified: I'll quote an authoritative source that said there is going to be an airborne Doppler wind shear program and at this point in time, I...

(Unintelligible)

Unidentified: I don't think we need the backup and try to justify the existence of this right now. I think we need to accept that somebody somewhere said that there is going to be such a program, and then, picking up from that point on, say, so, this is a flow chart that gets to the sensor.

Unidentified: ...airborne wind shear systems that are carried on the airplanes and we are putting LLWAS's in as fast as we can on the ground. They complement each other. If the ground system says there's shear, it is trans mitted to the pilot; if his own system says there's a shear, that is available to the pilot.

Unidentified: I think the answer really is that, in addition to the advisory information he now gets, we want to give the pilot some analytical ground-based information on which he can base his decision to go around or land.

Unidentified: In that box you just drew, we could draw little boxes hanging off of that, to say JAWS, MIST, and whatever these other acronyms are.

Hildebrand: I think JAWS ought to feed directly into the atmospheric model. Right, that one straight across, and then right under that draw a MIST box, right underneath JAWS. That should feed both into the atmospheric model, the same place JAWS does. Now a dashed line into refined atmospheric radar simulation. Maybe a solid line, which is another line, it goes, keep going, into there.

Robertson: Do we find atmospheric models that might be the MIST program down there? You could draw MIST and JAWS hanging off of that. I think there is going to be a lot of feeding in all of these programs combined together. See, what this says to the guy is that what he is doing now is right, and he needs to keep that up. He can't go over there and borrow a whole bunch of money from that program and put it into this program or he's shot himself in the foot.

Campbell: There's the possibility of taking some of the hardware, like Leo is saying, and feed that in there too.

Robertson: Yes, sure.

Hildebrand: They should be down in the data collection area, those two, instead of up on that line.

Unidentified: We're talking about MIST follow-ons.

Unidentified: MIST-2?

Unidentified: Well, maybe Wallops-1!

Lytle: That can also be used not only to collect the clutter data, but that type of hardware that can be used in simulation validation. But your technique, much of it could be changed for a required program or a second stage; it could not only give you the clutter data, but it could be used for other things.

Robertson: In order to keep this as a timeline chart, I think maybe this is the JAWS and MIST. Then the ground clutter data collection also comes around here and continues to be used, and that's your point.

Lytle: It is not just a single purpose for the ground clutter.

Robertson: It is a continuing effort that can be used to provide further validation of the ground clutter model.

Lytle: The algorithms you may have developed, you can install those, and use that hardware.

Hay: To get to a quick point, remember, JAWS on that side and these others are generic representations of a lot of other things that are going on. You are dealing with British Airways and Alan Whitfield and R. A. Bradford and twenty-six 747's that they have been backing up.

(Unintelligible; several speakers)

Unidentified: Now if I could make a suggestion: since this is Schlickenmaier's meeting, I would like to say that now this has created a beautiful flow chart for how you create a blade part of a shovel, but it doesn't have a handle yet. What you need to do is take this chart with the embellishments that Tom and Leo and whoever is going to put on it. You need to take that and show another line parallel to it along the bottom of the wall there, that says, now Mr. Blake, when we get to this sensor, it is not going to do us any good to display raw data in the cockpit. We need a parallel path along here that deals with working...

Bowles: What that does is establish feasibilities for that report. Now we are talking about the flight system technology that integrates the other sensors on the airplane.

Hay: Neal has that diagram, does he not?

Bowles: What we have done is to embellish that point.

Unidentified: This is the response to what he has asked for. This is the part that he has been uncomfortable with up until now, and I think the presentation on Friday should focus on this--showing him there is a light at the end of the tunnel and there is a path to get there. But for Schlickenmaier's purposes, I think he needs to be convinced that this is one element in a bigger problem to get you to the next box downstream, which is a workable installed system.

Unidentified: So then, there's a bottom line that addresses the questions of procedure, display, and cockpit integration.

Bowles: I think as this unfolds as time goes to left or right, we begin to fill up back where we took exception to Schlick this morning, system requirements from the aviation side. What happened two weeks ago, we came in that door, that is the door we came in up there in terms of some candidate possibilities, and Neal then identified this as, hey, I want to know more specifically about this one input.

Robertson: As far as defining the system requirements, normally before you go to invent something you've got to define what it is you are trying to invent. I think maybe that listening here, we've maybe jumped beyond deciding to invent it, but we don't know what it is, so I think maybe it might be appropriate to just put goals, and I think of this airborne effort. We have talked about what are really the crucial parts of the flight profile that are dangerous. Below 2000 feet, 40 seconds in front of the aircraft, and on takeoff and landing, and I think we want to be correct, so I think it could be stated in some very simple goals: design goals that just have a certain flight regime. Then have that as a system requirement.

Campbell: Could we summarize things right now, maybe in bulletized fashion?

Bowles: Now that we have gotten to this point, can we add to this?

Hay: Exactly what you added to the other one and that is what you told me before.

Bowles: Right, but can we really add to this, based on the dialogue to this point in time? It seems to me that we are saying that we have covered item two there. The program that Langley has proposed is going to stimulate and accelerate the development of the remote airborne sensor. That's a benefit along with capability.

Unidentified: I think a chart like this, plus the diagram just held up, would be an excellent way to get into this specific presentation that Tom, or Leo, or whoever is going to be giving it, to back him up to two weeks ago Thursday and say, here is a proposal for a program that is a systems approach for solving problems, that has all of these elements that are addressed: cockpit displays, integration of other sensors, you know, everything, and then you ask us about this board right here. When we were last here, you homed in on this question and asked us to come back. So now, I'm going to sit down and these guys are going to give you a presentation on just that. The bets set the stage point. He understands that he is not looking at a program that is the end of the whole, you know, it is the whole proposal effort. It is part of a bigger shove. I would like to see him start that way. Either you or Herb or somebody set the stage with two viewgraphs like this.

Hay: I would hope that the meeting goes on for the airborne part of this new program; they are the ones that are responsible for the whole thing and we make the introductions and so on, and walk into it and everybody would march off the floor.

(Unintelligible)

Schlickenmaier: (Unintelligible)

Schlickenmaier: What I really would like to be able to do, and this I think is a kickoff of a format on how we might be getting together with some of the other organizations, is to put together some program planning sessions with some of the different divisions and different program offices. What do the various relationships look like, and how could I put together a detailed program plan that I could justify on a budget line? I'm going to have a lot of help. That is a lot of help to be able to walk in and put in perspective a program to do a piece of the program budget, but a piece in which Neal is vitally interested.

Hay: Not only will you be working on the budget line, but NASA here will be working up their part, whatever that may be, as a parallel effort...mostly going forward to Congress with an agreed-upon program and agreed-upon input to that whatever you call it.

Verstynen: In other words, it means the full intent of the inter-agency agreement, and don't forget NOAA, and the part that they might play in fitting in some of those dependencies that you have shown.

Schlickenmaier: I think you guys can give us, with some amount of detail, some looks at technical risks in terms of probabilities in lines that may show us other than strictly time critical paths what some of the technical risks would be.

Verstynen: I would like to suggest that what you have there is an excellent approach. Now, you need that next charge to the goal.

Lytle: Roy, are you trying to make up another one of those slides?

Robertson: No, I'm just trying to copy this, in case some horrible eraser comes out of the sky.

Staton: Well, why don't you go write the goals up there, then five years from now we can blame it all on you!

Schlickenmaier: The goals in this case should be in terms of the radar development project.

Campbell: Some of the subsets of goals: There are motherhood goals, there are technical goals, it would be good to list these all out.

Verstynen: I think, we don't want to go too deeply back into Roland's presentation, his goals are at the systems level, at the overall program level. We don't want to rehash that too much. Just enough of

Roland's early presentation to give this a context, then focus in right onto the airborne Doppler radar.

Hay: Well, you had them on the board just a little while ago: general goals, operational goals.

Bowles: If you had to go ahead today, you would feel pretty comfortable in some of these areas. In the area that we don't feel comfortable in, there is no money available for early-on hardware, for example. We have got protytype sensors existing; we have got atmospheric modeling. We've got smart people that know how to do radar modeling, at some level in detail. But, what we don't have is the hardware option open.

Lytle: Well, we're not adequately talking about those things in terms of the atmospheric modeling with the radar offset reflectivity signal, to build the data base.

Verstynen: We're not adequately funded to do that.

Hay: Roland, didn't you hear about two months ago about an alternative determination of what you would do with an amount or level of funding if it was available to you? Which included what you might do in the TCV at one level, what you might do in another activity as well, or at other levels?

Bowles: Yes, I didn't show that chart. But, yes, we broke out what we'd do at the various levels. Leo would tell us that it is kind of obsolete based on the recent new inputs from electronics people.

Verstynen: Is the exercise you are referring to the one that we got involved with, is that the same?

Bowles: Yes, the one up in Washington. The only minor difference between what you just said and what I perceive actually happened was that we were not asked the question, what could you accelerate, given this level of funding, or this level of funding, or this level of funding? The question was more general than that, it was, what can be done to accelerate the program at Langley? The answer that you came back with was, that it depends on how much money you are talking about.

Hay: They both changed it in the meeting. He took it beyond that initial question, did he not?

Verstynen: The answer was if you are talking 50 K, then you know there are only a couple of little things that can do.

Unidentified: Yeah, 50 K might just cover Leo's travel budget!

Unidentified: Really?

Unidentified: It's what he does once he gets there! But, if you are talking 500 K, now we are into the realm where we can start looking at automatic approach and departure...

Hay: Well, that is what you are summarizing, Harry; it's exactly what we have done, and this was done about two months ago, I guess, when it was all put together before the question was asked.

Bowles: We could do that; I would just say that I think Leo would agree that this area of the radar is so obsolete based on the new input over the last week, it needs to be updated.

Robertson: How much is it going to cost to solve this problem, right? In the most expeditious manner that we can, we are going to accomplish this goal for this amount of money.

Verstynen: Those are probably two important points to make in the briefing, that don't just jump out from the chart. One is that if we are talking about acceleration of a program like this, above and beyond what Leo showed on his chart, is, what is going to happen if we just continue at the pace we have right now? If we are talking about acceleration of that, that there is a certain minimum buy-in; 25 K is suggested. It takes X number of dollars to get these things going, and if you accelerate down one path and don't carry along the other paths, then in the end you really haven't bought yourself much. I don't know how you put that on a figure, but that is one important point I think you need to get across. The second one is, you drew a present-day line up there a few minutes ago, with the implication being that present-day really is the beginning of all those boxes--when, in fact, I think the point Leo was trying to make is that we are really nine months away from anything happening because of procurement lags, and so, the person who is anxious to get something going ought to take that initial lag.

Hay: You've hit on it exactly, right there.

Bowles: This is not starting with a dry hole trying to find oil. Leo does have a budget, though under scale, out of OAST. You're funded, so there is a base of dollars in '86 right now, and as we finish '85.

Verstynen: On that line up there that says radar model and atmospheric model, that kind of work we are indeed at the beginning of the box. But down where it says hardware procurement, and I don't know which of those boxes...

Hay: I think your point is well taken, Harry. What you need to do is to point out the areas that you need your support in to be able to move it on or not.

Verstynen: Maybe all those boxes really are not aligned in time, just the way they are shown there. Some really are just down the stream a little bit because of procurement lags and things like that.

Hay: I would like to insert something here. Where does private enterprise come into it?

Lytle: I think one of your goals should be to establish a framework that could allow all the people to get access to the data and to contribute to the data.

Hay: It seems to me that the government's primary job is to get the research tools and equipment to get the data, and it's up to private enterprise to use the data to generate the wind shear sensor, because they are the ones who are going to make it and produce it in the end, anyway. I was just wondering, where is private industry? Like, where Boeing is today, where Sperry is today, where you are today?

Unidentified: I was just wondering why aren't they at the meeting here?

Schlickenmaier: This meeting could have been huge, if we started dealing with all of them right off. But there are many facets to the problem, and those people need to come in as we get to each new phase. I think when we get to flight management systems, and some sort of guidance and control, we will obviously call on these various companies.

Campbell: Is there anything that private industry would be willing to allow government to participate in, as far as you know?

Hay: That is an area I'm not too familiar in.

Campbell: Simulation models, do you have anything like that at Collins?

Robertson: I would say, from my point of view, no. No, we really don't have much aside from the statement of what our needs are, to proceed with the development. I don't think we have any products in house. I think the research institutions have been a lot more interested.

Campbell: What about reviews of IRAD? Do you have an IRAD program?

Robertson: Well, I think, I guess I don't know. I think the best I could do would be to search within the company to see what kind of cross-fertilization is going on there.

Schlickenmaier: Is availability of this type of service or radar simulation activity for people from Collins to come in and tell people like Teledyne, Sperry, etc., "This is a modeling exercise I would like to learn." But what kind of surprises we might find, I don't know, because we rarely sell our services commercially.

Unidentified: This fits well within the...technology base, and the technology transfer to industry.

Unidentified: Part of what the government underwrites in this program.

Campbell: But I'm trying to get the arrow to come the other way as well. You have got the private industries going across the top; the arrow should feed down to the government as well.

Hay: Well, private industry doesn't have a lot of that data. You know their primary interest is...

Campbell: The IRAD's and stuff like that may be a framework.

Schlickenmaier: If we can really be bold, I think we have got something established for the timeline. In fact we are talking about and realistically putting together simulation facilities.

Campbell: Yes, but industry represents a lot of information, especially in the black world. I know that they listen but will not talk, but somehow we need to get some feedback.

Schlickenmaier: We're talking about starting to realize the costs of this project. We're not just talking about doing research because it's neat; we're talking about maybe putting a product out, eventually.

Hildebrand: With something like end products, like timeline to a certifiable device, and with facilities available such as this, I think you're going to have a hard time keeping a lot of these people from...

Robertson: The information transfer will be in the form of, well, can you give us this, we have found this data from the data you have given us before and maybe a little different slant to it, or another type of data. I think it is going to be an iterative process to arrive at that middle box, the multiple design tool for the whole simulation. It is going to be in pieces as we go along.

Schlickenmaier: The only thing I really emphasize is the experience with the wind shear model data base. There was a lot of cooperation with the private sector. Once we make these models available to people, there will be information coming back, not as much as we would like, but there was a fair amount of information coming back, because of the time we had to set up.

Campbell: I would hope there could be similar boxes above the central level that would involve simulation by industry, as well as backup. Contact made by the FAA and NASA to the right DOD people would make a nice contact so that those simulation models with a ground clutter suppression technique that somehow works can be fed into this national wind shear problem.

Hildebrand: You know, there is a mechanism that people have been addressing. I don't know if you have heard this in NASA or FAA, but we had a request come down, somebody or other asking NSF, our primary funding agency, he asked, are there classified data that you need to get to to solve technique problems you are working with? That was the question we were asked in the last six months. You know that there has to be classified data regarding ground clutter from airplanes that are moving at very high speed and very low altitude; there is no question that that exists. If NSF was asking the question, there are presumably other agencies that have been thinking about that. Is it possible to get those data in such a way that the military doesn't feel that they've been compromised? If so, there is one area that could help a lot. I imagine that the antenna area is another area.

(One-minute discussion on responsibilities of industry and of government in developing and disseminating a data base)

Robertson: I would say that that data belongs to Hughes and Westinghouse.

Campbell: If you put a dotted line across that map, and you put private industry above that line and government below that line, will all those top boxes be private industries?

Robertson: No. I think you have the line in the right place. All of the boxes along the top row are private industries. Then they come together as an end product.

Campbell: That would be good to show to a guy like Neal Blake, wouldn't it? Put a dotted line across here and this is the government contribution, this is what industry contributes.

(Numerous simultaneous comments)

Lytle: The prototype sensors, I'm not sure you want to say that's totally the responsibility of industry.

Robertson: So, that line goes through the middle of this box.

Lytle: Well, I think what you are trying to establish is the framework so that private industry can put their requirements in, and their contributions in, in any of those areas.

Unidentified: So many of the activities will be shared, but there will have to be a certain amount of duplication. Like sensor refinement.

Hildebrand: The problem that is going to happen is that the industry component goes up as time goes on, and the government component comes down in that area, but it is going to be shared.

Campbell: Maybe you should crosshatch those blocks that show shared activities.

Hay: Perhaps what Peter is saying, you just start in the upper left-hand corner without any definitions of blocks, but you show a dotted line diagonally down across the entire graph, and just demonstrate there a shared responsiblity to the government and industry; the government input reduces with time and the industries' part increases.

Hildebrand: And, I think that's an accurate representation.

(Unintelligible)

Hay: And how much it is, that's another matter.

Hildebrand: You are also going to find industry involved in simulation and simulation validation, so that your dotted line is really going to start off somewhere near where sensor development is written, and it is going to end up somewhere near the middle of the simulation validation box, or somewhere in that general area. And people are more eager to get in earlier on different things, and there are going to be other people who like being behind the power curve, and they are going to come in at the last minute.

(Unintelligible)

Hay: How can we help? If you have a requirement, then we will cooperate with you. Otherwise, we are going to wait until you decide what to do, and then we're going to follow you.

Campbell: Let's talk about the funding line over there.

(Unintelligible)

Schlickenmaier: Whatever the funding requirements are, that's something that we're not prepared to do yet.

Campbell: Does the acceleration of funding depend on OAST?

Schlickenmaier: In a sense, I guess it does--in that you've got some FY 86 funding already earmarked.

Campbell: We have had no idea what the outlook to that contributes to OAST funding until these recent comments that reference what Lee Holcomb said.

Bowles: I think that the marketing guys, Collins or Teledyne, or whoever, will look at the bottom line over here and say, "Hey, that's nice," until Roy and other people tell them it's going to take two million dollars a year to fill up that middle row. They're not going to underwrite that kind of development cost over four or five years. What the government is doing is to say we want to help underwrite it, and provide products to allow you to achieve your niche in the marketplace. The other half is very important. The way OAST looks at that, is they like to be loved. If they are going to support programs for NASA, they have to feel wanted. First thing they want to know is, who wants that product? I hope industry is prepared to say, we want it.

Hay: Don't you think that as far as integrated programs go, all of the major carriers in the form of ATA, ALPA, AOPA, all of the major aircraft manufacturers are going to have to have a hand in it, and feel comfortable with it before it's submitted? The answer to that is yes. The answer to the second part is that they have been, and the third part of the answer is they do. So, unless you do your homework, you are going to sit here all day long and say the government ought to do this and that. Until you stand up and be counted...

Robertson: That's an important point, because we're not always atuned to the workings of what it takes.

Hay: Are you going to put that one on every program in existence, and feel very comfortable with that?

Robertson: I know what it takes to sell something of value.

Hay: Every airline I have gone to says exactly the same thing. They are no longer a public utility. We answer for every minute of simulation, every penny we spend--not to aviation-minded people, but to the financial guys. And we're in much the same program as the OMB.

Lytle: Are you really saying that this is a simulation facility in the same sense as the aircraft simulation facility or a radar wind shear simulation facility that can support industry?

Robertson: Don't they fit together, though?

Schlickenmaier: Yes, I would call it a radar simulation facility, a math modeling facility. I don't think we're talking about the pilot-in-the-loop mode, but in the same sense as, say, selling time to Boeing, to work on the TCV simulator, and other advanced concepts. I would imagine that if someone wanted to come in and buy time, that it would be a flexible enough system to do work on wind-shear-related and atmospheric-anomaly-related radar research.

Bowles: Well then, I parallel it along sort of like NASTRAC. As a matter of fact, it's a data base; it's a model; its capabiliity is not small and trivial.

Unidentified: If Collins has an approach, for example, a modulation technique, they might want to try detecting wind shear with clutter, then would you have a facility where you could bring the technique in?

Robertson: I would say, that is one scenario that I would view the end product of this simulation capability to be the information, the science that backs it up, the algorithms for the atmospheric/radar interactions; that's the product. That may very well be the best end result that we have, a simulation facility that we can use, and I think that would have to be maintained here in order to develop the science behind it, but in terms of using that as a tool, we may very well use that back at our plant. But the end product is the data base, the information, the algorithm, the software that generates these models, all of this stuff. That is the part that has not been all married together. There are lots of pieces existing, coming from a lot of different sources. When they all get integrated together, it becomes a facility.

Unidentified: Of course, if the government does it, then it's public domain.

Robertson: Yes, that's right.

Schlickenmaier: The highest priority, from my point of view, looking at the whole system, is the area of detection of wind shear. I think, as we were just talking about before, establishing this government/industry framework, how can we come up with reasonably sophisticated software packages...which require that some procedures be set up?

Bowles: It's clearly defined within the realm of possibilities. I don't think NASA should get into the transportation business.

Unidentified: No, absolutely not. The information that the corporate data base that exists at Langley is...by the time government is washing out, industry is washing in. You know, you've got something that needs to be looked at, and a framework for how that information is exchanged.

Bowles: OK, maybe the gold then, under an established government/industry framework, is clearly defined. That is the gold. We need to clearly define it.

Unidentified: You need more than that. You need a way for them to contribute to and respond to defining the types of data.

Bowles: I guess we could lump that all under technology training. That is a two-way street.

Campbell: This might be a little naive, but is it possible to establish an industry steering group that works with the government team? On space station right now is an industry steering group established to help tell the agency how to design and build a new space station.

Britt: Does RTCA have a committee on this subject?

Hay: Well, RTCA, I believe, has an interest, but not a committee, but SAE types have a number of interests. The whole thing there is the slick problem of being...in some way so you won't have this committee looking here and that committee looking there, and...

Schlickenmaier: If you talk to Charlie Cape, working on an NOS project, some of the synergy we've been working with NSC 151, and the capabilities that have been set up here toward an interagency agreement, have made that special committee take off and run. That was one case where somebody said they've got to put together this special committee, and then some facilities were established that would work, and so these facilities were established. So they came down here and saw that it was working properly, and they started focusing attention. It works well.

Hay: The focus for this activity in this area I think is getting very good and very dynamic. It could be pulled together.

Campbell: Herb, before we break up today, is it possible--this is beside the point, it goes back to the point John Fedors brought up--could we kind of prophesy the sensor performance requirements as we envision them today? Maybe four or five bullets? What we think is certifiable for wind shear sensing? What is the performance? What do you want it to be?

Hay: You have got area protection; why don't you just put a subset or another full one, and call it performance estimates. I don't know what appropriate word you'd use.

(Unintelligible)

Robertson: I think this is a very key part of the whole project, defining what the performance requirements are, because I can see going along down the timeline that there are going to be, like what we talked about yesterday, incremental improvements to existing things in service now.

(Unintelligible)

Campbell: Can we take a shot at those right now?

Robertson: No, the performance requirements, maybe for the end solution, might be something; there may be several iterations to get to them.

Hildebrand: I think the problem with taking it is that we could start out by saying, tell me if I'm being pessimistic or not, but we need to be able to detect a minus 20 dBZ microburst in 40 dB ground clutter, and specify the range of velocity. Now that is a project in itself, or a specification that is...There is no light at the end of that tunnel right now. That is a black tunnel, but at the same time, if we are going to specify where we think it might go, it's realistic to say that, and I'm concerned that you...(interruption)

Campbell: Yes, that is a goal. Why can't we write that down?

Hildebrand: My concern is that as soon as we say that--and I think that is a realistic statement to say that if we are going to measure all microbursts accurately, we are going to have to do that kind of problem--as soon as we write that down, we've just shot ourself in one foot or the other, and the question is how do you hobble along till people realize that there are some interim steps that are worth making?

Hay: What you are describing there was a radar problem. What I think we want to do up here is describe what we want the radar to do, not what the radar is going to see, because some radars may not see that particular clutter problem that you mentioned. When you said it should do this in 20 dB of clutter, one radar may have miserable sidelobes, and when it gets rid of that clutter it still can't see that microburst, while another radar with good sidelobes can see it real easily. What we need to do is to describe what their systems should do; not say, now the radar is going to have to get rid of this much clutter.

Hildebrand: Now that is the designer's problem.

Hay: We have to have some idea what the operational response should be to make it useful to us. The details can't be discussed, because they have to be developed as we go along with the operational people. The details of the radar development, the technical details, etc., looking for some kind of performance capability in critical operational areas, that you have to work here to find. Resolution and range are some of the details.

(Unintelligible)

Robertson: Those are details. What we want is a probability of detection and false alarm rate. Those are the two criteria.

Hildebrand: If you carefully define range and not talk about reflectivity, I think you are begging the question, so yes, that is OK. The idea that you are going to look ahead to do this is OK.

Campbell: Looking ahead how far?

(Unintelligible)

Hildebrand: Now, it would be all right with me if you said, we're going to establish a phased approach that is going to look first at this kind of problem, and then another, and show that there is a tractable route to solutions. Then, I would begin to think that it is all right to do some specification.

Campbell: What is wrong with that? Are you afraid of anything?

Hildebrand: I'm not afraid of doing that as much, as long as every number we write down here is the number we realize is the number we have to go back to for our atmospheric model, and we have to get to the real experts on microbursts to put them in.

(Many persons discussing whether or not to quantify the expected performance of a proposed system)

Campbell: It would be good to have a few numbers out there, so the guys who are going to start off on these simulation studies have enough information to go on to do something about it.

Staton: Yes, but those people are going to come up with their own numbers. They are not going to pay attention to anything that we put up on the board. And if anything you put on the board sanctifies it, then it will come back to haunt you later.

Hildebrand: Look, we can sit down and we can say, you want to see a velocity gradient of thus and so, at a distance of such and such, from the ground, having a reflectivity, OK. So you want to have a specifiable velocity gradient you can detect. You want to specify the reflectivity of the meteorological target. You want to specify the reflectivity of the ground, and the proximity of the ground to the meteorological target. What else do we want to add to that list?

Britt: I don't think you want to specify any of those things.

Unidentified: Weren't you the one that said that you wanted to cover a sector as opposed to straight ahead?

Lytle: What you can actually accomplish will be what is ultimately put in. In other words if you can't get your rep rate up to cover the desired sector, then you'll probably narrow your sector down to see what you can do. So if you say we are going to cover a 20-degree sector in front of us, then if you say that, then anything that doesn't accomplish it means there's been a failure.

Hay: We can take care of that by calling that "design goals." If this is your design goal, then you usually supplement that by saying absolute requirements, because if a radar can't do at least a certain minimum, then you can't call it a shear detection radar.

Staton: Any design goals need to wait for the next workshop. We shouldn't do that today.

Hay: Well, then radar people aren't going to do anything.

Hildebrand: I think we can complete a list of design goals. The thing I get uncomfortable with is putting numbers on those goals without thinking about them carefully. Now, in the proximity of the meteorological target to the ground, the probability maximum of the velocity of the meteorological target is something you're going to have to assume, and aircraft capability will specify the sector you have to scan or measure, of target and aircraft. Then from that, you are also going to need to specify a reaction time model for the flight crew and aircraft. Then based on that, the last thing is, based on aircraft and air crew. You push the throttles; it takes a while for the engines to spool up. The final thing then is the domain you make measurements of. With the radar, how far out do you scan? The radar range; it has to do with the elevation and azimuth angles.

Robertson: We are starting out by defining the event we are trying to detect. Then we say what about that event, what causes it to be a dangerous event, and what is our velocity gradient, etc.? Then we ask, what is our probability of detecting that event? That probably never will be a hundred percent.

Unidentified: Just like we can't fly through every wind shear.

Hay: Now that second from the last suggestion there, I don't think that, from that, you determine what the other parameters are--reaction time, you know, the guy who was designing the radar, you know, that is not his problem. The reaction time determines what range you have to look for. That is what you need to determine your parameters--also, threshold, and aircraft performance.

Unidentified: Let's not oversimplify the world, so that we're left with a null problem.

Bowles: I would encourage you to say velocity gradient.

Hay: Better to say velocity gradient of what? Microbursts?

Bowles: Of wind shear phenomena.

Robertson: Another element that is missing over there is the false alarm rate. If this thing is going off on every approach, then that's not good.

Staton: What does this list do for us? There are just some considerations for this problem. Maybe, instead of doing this right now, we need to interpose along the timeline some scheduled workshop that evaluates progress.

Unidentified: Leo, that is right, but this sells the program initially for you.

Staton: We need to convince them that we are going to protect the airplane on takeoff and landing, that is what we are going to do.

Unidentified: They are not going to buy that kind of general statement.

Unidentified: You're right. You're absolutely correct.

Staton: But, I don't see that this helps anybody in working on the problem.

Hay: But it helps the guy designing the radar.

Hildebrand: These are sets of performance specifications for the radar. They will be derived from specifying all of these things here.

Staton: And dozens of others we haven't thought of.

Hildebrand: Notice we haven't written any numbers down.

Verstynen: Leo is looking down instead of up right now, and in the sense of from your level looking down and hardware development and making things happen, this isn't a very useful list. If you are at a level where we are looking up, trying to get a program going, this does a beautiful job of scoping out what the problem really is.

Schlickenmaier: The people we'll be talking to are nowhere near the capabilities. We are talking to people who are not only looking at wind shear, but at the FAA level, we are talking to people who are concerned with landing systems, data link implementation, a number of programs that use words like safety. And when you go up to the next level, you are you are looking at air bag issues, looking at railroad safety issues, across all transportation safety issues, and all we have done here, is say, hey guys, when I talked to the committee on flight status monitors, safety issues, what is it for? They then say, where have you been all of this time? Then I had to put myself into context of all the other transportation modes. That is the kind of people we are going to be dealing with.

(Unintelligible)

Unidentified: As you probably know, I am pretty much interested in what finally gets through to the pilot. It has to be simple. I propose a number of considerations, and this is only one item on the list: that is that it be compatible with other parts of the system; for instance, it could be in situ, on the ground.

(Unintelligible)

Unidentified: There are simple versions of detecting and alerting systems proposed. And the simple systems work. And we should really look at them in terms of what is presented to the pilot.

Schlickenmaier: That's an overview. That's at a higher level up.

Unidentified: I say this because we should have our blinders off. We shouldn't have blinders on. Keep our eyes open. We've got to be aware of what others are doing.

Campbell: That looks like a pretty good list. The fact that bothers me is that you have got more work than you have money, and you have to involve a lot more other people in this problem who have not been involved in microburst measurements by radars and all of that stuff before, and even in the area of electromagnetics and antenna design, you have got to have enough requirements to define adequately, so they can go off and work the problem and see if they can contribute. Maybe they can contribute their thing. Somebody has to involve enough people in this thing, and it's got to be presented in a manner that it will be sold, to involve other organizations and enough people to do the job. I think that might fall under the very bottom under goals. That has got to be a product of this effort, and then to define whatever industry or agency resources are required.

Schlickenmaier: I think that in the January-February-March time frame there might be the possibility of doing some workshops.

Bowles: I would suggest that we start calling this whole effort "wind shear radar." It is a wind shear radar program. That is exactly what we are focusing on.

Campbell: How would the radar manufacturers feel about that?

Hay: I could argue that probably when industry gets into it, they won't just build wind shear radar sensors, because it's only used once in a lifetime. It will be built into a more general radar.

Unidentified: Then we elevate it to multi-purpose wind shear radar. As a matter of fact, if we get into the hazard definition area, we look at how we integrate that information into flight status monitor systems.

(Many persons speaking simultaneously)

Hay: Maybe it's a good selling point right now, but you may change it in six months.

Robertson: We need to differentiate this from LLWAS and other kinds of wind shear sensors.

Bowles: How about AWSR, as opposed to TDWR?

Unidentified: A new acronym calls for another workshop!

Schlickenmaier: (Closing statements acknowledging the degree of cooperation at this meeting, and the good working relationships established)

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16. Abstract

In response to the Nation's needs for decreasing the threat of violent weather phenomena to aviation, a two-day meeting was held on September 24-25, 1985, at the NASA Langley Research Center. This meeting, which brought together representatives from NASA, the FAA, and the avionics industry, focused on the applicability of Doppler radar techniques to the detection of low-level wind shear. The meeting was cohosted by the Antenna and Microwave Research Branch of NASA Langley's Guidance and Control Division and by the Cockpit Technology Branch of the FAA's Navigation and Landing Division. This publication is a verbatim transcript of the presentations and discussions which took place during the meeting. Limited editing was employed for the sake of clarity.

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